which they are based is not stated. For the purpose of meteorological charts, the inaccuracy of considering the earth as a sphere is unimportant, and the differences between different ellipsoids are negligible; but if an ellipsoid be used, presumably it should be the International Ellipsoid, on which table 1 has been computed.

TABLE 1.—*Scale variations*

| Latitude | Mercator [1] | | Lambert [2] | | Stereographic [3] | |
|---|---|---|---|---|---|---|
| | Sphere | International ellipsoid | Sphere | International ellipsoid | Sphere | International ellipsoid |
| ° | | | | | | |
| 0 | 0.924 | 0.924 | 1.283 | 1.281 | 1.932 | 1.860 |
| 5 | .927 | .928 | 1.210 | 1.208 | 1.777 | 1.712 |
| 10 | .938 | .938 | 1.149 | 1.148 | 1.590 | 1.586 |
| 15 | .956 | .957 | 1.099 | 1.098 | 1.482 | 1.480 |
| 20 | .983 | .983 | 1.058 | 1.058 | 1.390 | 1.388 |
| 25 | 1.019 | 1.019 | 1.025 | 1.025 | 1.312 | 1.310 |
| 30 | 1.067 | 1.066 | 1.000 | 1.000 | 1.244 | 1.243 |
| 35 | 1.128 | 1.127 | .982 | .982 | 1.186 | 1.185 |
| 40 | 1.206 | 1.205 | .970 | .970 | 1.136 | 1.136 |
| 45 | 1.307 | 1.305 | .966 | .966 | 1.093 | 1.093 |
| 50 | 1.437 | 1.435 | .968 | .969 | 1.057 | 1.057 |
| 55 | 1.611 | 1.608 | .979 | .979 | 1.026 | 1.026 |
| 60 | 1.848 | 1.844 | 1.000 | 1.000 | 1.000 | 1.000 |
| 65 | 2.186 | 2.181 | 1.033 | 1.033 | .979 | .979 |
| 70 | 2.701 | 2.694 | 1.084 | 1.083 | .962 | .962 |
| 75 | 3.570 | 3.560 | 1.162 | 1.162 | .049 | .949 |
| 80 | 5.320 | 5.306 | 1.293 | 1.292 | .940 | .940 |
| 85 | 10.600 | 10.570 | 1.566 | 1.564 | .934 | .936 |

[1] Standard parallel, 22½°.
[2] Standard parallels, 30° and 60°.
[3] Standard parallel, 60°.

The Commission suggested in the eighth resolution that equal-area charts be used for climatological purposes, i. e. maps in which the relative areas of different regions are correctly represented. These would include the azimuthal equal-area projection for the polar regions, the equal-area conic projection (Albers') for middle latitudes, and the cylindrical equal-area projection for the equatorial zone.

In middle latitudes it makes little difference for meteorological purposes whether the conic projection for 30° and 60° is conformal (Lambert) or equal-area (Albers). They are so nearly identical that it is difficult to differentiate by inspection. For this reason, the eighth resolution contains the words "when special charts for climatology are required." Some meteorologists expressed a desire to use (for climatological purposes in middle latitudes) the conformal projection already employed for synoptic purposes, rather than prepare a special map on an equal-area projection that differs so little. Scales were not specified.

The ninth resolution requires no explanation.

## CONCLUSION

While much remains to be done before complete uniformity is attained in manuscript and printed charts for meteorological work, the Salzburg resolutions, if adhered to by all meteorological services, will result in marked progress in that direction.

A review of action in the International Meteorological Organization shows that at all stages there has been a decided preference for conformality and continuity as the outstanding properties of synoptic charts.

For climatology, projections of the same type as those recommended for synoptic charts are preferred, except that they should have true representation of area rather than conformality.

In the future we shall certainly find meteorological bureaus extending their charts to cover large portions of the earth's surface, and in all probability the beginnings of daily charts of the whole world. These developments will necessitate more extensive international exchanges of weather information and more intensive standardization in collection, distribution, and charting of the data. The Salzburg resolutions on projections and scales of charts provide a sound basis for future expansion.

## ACKNOWLEDGMENTS

It is a pleasure to acknowledge the assistance of the members of the Commission on Projections for Meteorological Charts, and of officials of the United States Coast and Geodetic Survey,[10] in preparing the resolutions adopted at Salzburg; of the directors of weather services in providing specimen charts, and data on projections and scales in use in various countries; and of Edgar W. Woolard and Charles M. Lennahan in the preparation of the comments on the mathematical properties of the projections and the calculation of table 1.

[10] Readers desiring further information regarding the theory, construction, and properties of the projections are referred to the following:
Oscar S. Adams. A study of map projections in general, *U. S. C. & G. S. Spec. Pub. 60*, Washington, 1919. Charles H. Deetz and Oscar S. Adams. Elements of map projection, *U. S. C. & G. S. Spec. Pub. 68*, Washington, 1934.
Tables of the International Ellipsoid are contained in *U. S. C. & G. S. Spec. Pub. 200*.

# REVIEW OF UNITED STATES WEATHER BUREAU SOLAR RADIATION INVESTIGATIONS

By IRVING F. HAND

[Weather Bureau, Washington, D. C., June 1937]

The purpose of this paper is to present a summary to date of the methods employed and the results obtained in the solar radiation investigations conducted by the Weather Bureau. Many data are here published for the first time, while several tables and charts that have previously appeared in the MONTHLY WEATHER REVIEW are revised and brought up to date. Numerous references to the literature are included, to enable readers who so desire to readily locate further details (a useful general bibliography of some of the earlier literature is given by Kimball, *Bull. Mt. Weath. Obs.*, 3: 118–126, 1910).

## INTRODUCTION

Radiation from the sun is the ultimate source of all except a practically negligible portion of the continual supply of energy that is essential for the maintenance of plant and animal life on the earth and for the operation of nearly all natural phenomena on the surface of the earth; in particular, the amount and the distribution in time and space of the solar radiation which is intercepted by the earth is the primary generating cause of the physical activities in the atmosphere that determine weather and climate. The study of the radiation from the sun is therefore of direct and fundamental importance to numerous different fields of both pure and applied science, including meteorology.

The Weather Bureau first began to devote attention to solar radiation measurements in 1901. (See *Rept. of the Chief of the Weather Bureau*, 1901–1902, p. xvii; and C. F. Marvin, MO. WEA. REV., 29: 454–458, 1901.) In July of that year, three copies of Angström's electric compensation pyrheliometer were obtained, for the purpose of conducting researches on the amount of solar heat and its absorption in the atmosphere, and related questions. The first measurements by the Weather Bureau of solar radiation received at the surface of the earth were taken with one of these instruments at Asheville and Black Mountain in North Carolina from November 10, 1902, until March 26, 1903, by H. H. Kimball (Mo. WEA. REV., 31: 320–334, 1903), although the instrument had previously been used during 1901–02 at Providence, R. I., under the direction of Carl Barus (Mo. WEA. REV., 31: 275–280, 1903; cf. *Rept. Chief of Weather Bureau*, 1902–1903, p. xix). Observations were then continued at Washington, D. C. (*Bull. Mt. Weath. Obs.*, 3: 69–126, 1910).

When the Mount Weather Observatory was established, provision was made for a comprehensive program of solar observations; pyrheliometric measurements were begun there on September 21, 1907. Meanwhile, polarimetric observations had also been commenced at Washington. This earliest work is summarized in *Bull. Mt. Weath. Obs.*, 1: 82–93, 207–231, 1908; 2: 55–65, 214–224, 1909–10; 3: 69–126, 1910; 5: 295–312, 1913; *Jour. Frank. Inst.*, 171: 333–344, 1911; Mo. WEA. REV., 42: 474–487 and 650–653, 1914; 43: 100–111, 1915. As the desirability of expanding the work became apparent, additional stations were occupied, improved instrumental equipment obtained, and further types of observations introduced. The first new stations added were at Madison, Wis., where observations were begun on July 19, 1910 (*Bull. Mt. Weath. Obs.*, 5: 173–183, 1912, and Mo. WEA. REV., 44: 8–12, 180–181, 1916, which summarized the data for 1910–15); and at Lincoln, Nebr., November 10, 1911 (Mo. WEA. REV., 44: 5–8, 1916, with data for 1911–1915). Observations at Mount Weather were discontinued at the end of September 1914, and the equipment transferred to a station at American University, Washington, D. C. The data obtained at Mount Weather and Washington in 1914–15 were published in the Mo. WEA. REV., 42: 138–141, 310–311, 520, 648–649, 1914; 43: 112–113, 1915, and monthly thereafter; data from Santa Fe are given in the Mo. WEA. REV., 43: 439–443, 590–591, 1915. Since January 1916, data for all stations have been published monthly in the REVIEW. The Santa Fe station was discontinued in March 1922.

The data which have been accumulated during the continuous observing program that has since been maintained at a growing network of stations, and the results of investigations based on these data, are of fundamental importance in a wide range of meteorological, oceanographic, physical, engineering, agricultural, biological, and medical problems (*cf.* Mo. WEATH. REV., 48: 18–24, 1920); they have found extensive application, both in practical work and in scientific research, and there has always been a demand for further extension of the program:

Sunshine data have long been recognized as an essential part of a complete climatological record.[1] Pyrheliometric records of total solar and sky radiation received on a horizontal surface are correspondingly of still more value than the records obtained with ordinary sunshine recorders which merely indicate when the direct rays of the sun reach the surface of the earth with an intensity sufficiently great to actuate the instrument.

A knowledge of both the amount of solar radiation that is received at the earth and also its distribution during the growing season is important to horticulturists, botanists, and plant physiologists. With growing appreciation of this fact, the number of universities and other institutions that maintain stations to determine the amount of solar and sky radiation for use in their own researches, and who cooperate with the Weather Bureau by forwarding their data, is increasing yearly. An interesting example of the application of such data in agriculture is provided by the case of a large sugar-beet company which operated at a loss near the Great Lakes some years ago, because of the excessive cost of processing fibrous beets with low sugar-content. Belatedly learning the cause of their failure, they removed their plant to Idaho where the greater radiation receipt during the growing season enables them to operate profitably because their beets now contain sufficient sugar. Their former location is totally unadapted for this particular crop. Examples of recent researches which involve solar radiation as a direct factor are those of Johnston[2] on the correlation of plant growth with the components of solar radiation; of Meier,[3] who has investigated the effects of different wave-lengths of radiation on green algae; of Burk and Lineweaver,[4] who have unravelled many of the mysteries of photosynthesis; of Flint and McAlister,[5] who have studied the effect of solar radiation in promoting germination in seeds; and many others.

Solar radiation data likewise find extensive application in the heating and air conditioning industries,[6] in illuminating engineering,[7] and in connection with studies of evaporation for various scientific and civil engineering purposes.[8]

It is not inconceivable that in the future when natural fuel resources become depleted, solar energy may be directly used on a large scale for heat and power; it has already been utilized for these purposes to a limited extent.[9]

## SOLAR RADIATION INTENSITIES BEYOND THE LIMITS OF THE ATMOSPHERE

A complete study of solar radiation involves, first, the study of the sun itself—physical conditions throughout the sun, genesis of solar energy, properties of the emitted radiation, and their relations to other solar phenomena—which lies in the domain of astrophysics; second, the determination of the amount of radiation emitted by the sun, and its intensity distribution over the outer limits of the appreciable atmosphere of the earth; and third, the investigation of the depletion of the radiation while traversing the atmosphere, and the resultant geographical intensity distribution at the surface of the earth.

The immediate interest of the meteorologist is in the dynamic and thermodynamic effects of the energy trans-

[1] See Joseph B. Kincer, Sunshine in the United States, Mo. WEA. REV., 48: 12–17, 1920; R. DeC. Ward, Bibliographic Note on Sunshine in the United States, Mo. WEA. REV., 47: 794–5, 1919. U. S. Depart. of Agric., *Atlas of American Agriculture*, Washington, 1936.

[2] Earl D. Johnston, The Functions of Radiations in the Physiology of Plants. *Smith. Misc. Coll.*, v. 87, No. 14, 1932.

[3] Florence E. Meier, Effects of Intensities and Wave-Lengths of Light on Unicellular Green Algae. *Smith. Misc. Coll.*, v. 92, No. 6, 1934.

[4] Dean Burk and Hans Lineweaver, The Minimum Kinetic Mechanism of Photosynthesis, *Nature*, 135: 621, 1935.

[5] L. H. Flint, The Action of Radiation of Specific Wave-Lengths in Relation to the Germination of Light-Sensitive Lettuce Seed. *Comptes rendus de l'Association Internationale d'Essais de Semences*, No. 1. Copenhagen, 1936.

[6] See, e. g., the applications discussed in *Trans. Amer. Soc. Heating and Vent. Eng.*, 36: 137, 1930; 38: 231, 1932; 40: 101, 1934.

[7] The volumes of the *Trans. Illum. Eng. Soc.* contain a number of papers on this subject. E. g., the data are of great value to architects and others in designing window space in schools, factories, etc., to secure adequate lighting and, in many instances, insure compliance with state laws. *Cf.* Kimball and Thiessen, Mo. WEA. REV., 45: 205–207, 1917, and Kimball, Mo. WEA. REV., 42: 29–35, 1914, on the influence of city smoke on daylight illumination.

[8] B. Richardson, Evaporation as a function of insolation, *Trans. Amer. Soc. Civ. Eng.*, 95: 996–1019, 1931. G. F. McEwen, Heating and cooling of water surfaces, Mo. WEA. REV., 56: 398–399, 1928.

[9] See A. S. E. Ackermann, The Utilization of Solar Energy, *Jour Roy. Soc. of Arts*, April 30, 1915; rep. in *Ann. Rept. Smiths, Inst.* for 1915. Some recent experiments on the utilization of solar energy are described in *Bull.* 602, College of Agriculture, Berkeley Agric. Exp. Sta.; *Scientific American*, April 1936, p. 197; *Science*, Oct. 19, 1934 (Science News, p. 8); *Annals Astrophys. Obs.*, Smiths. Inst., v. 4, ch. 9.

formations and energy distribution which result from reflection, scattering and absorption of radiation in the atmosphere and at the surface of the earth. The Weather Bureau has therefore confined its solar radiation studies to measurements of the amount that reaches the surface of the earth and investigations of closely related phenomena.

The determination of the total intensity and spectral energy distribution of solar radiation at the outer limit of the appreciable atmosphere has been the principal work of the Astrophysical Observatory of the Smithsonian Institution.[10] The rate at which solar radiant energy is received outside the atmosphere on a surface *normal* to the incident radiation, at the earth's mean distance from the sun, is called the *solar constant;* the value of the mean solar constant obtained by the Astrophysical Observatory, viz, 1.94 gram calories per square centimeter per minute, has been almost universally adopted, and has been used in all the Weather Bureau computations.

The rate at which direct solar radiant energy is received on a *horizontal* surface will here be called the insolation (this term is also used in other senses by different writers); it depends upon (1) the solar constant, (2) distance from the sun, (3) inclination of the incident rays to the horizontal, as determined by latitude, time of year and time of day, and (4) depletion to which the radiation has been subjected during passage through the atmosphere. When the solar constant is known, the determination of the distribution of insolation outside the atmosphere, by latitude and time of year, is a simple problem in mathematical astronomy,[11] and is of fundamental importance to physical meteorology.

As radiation passes through the atmosphere, it is in general divided into three parts: (1) One part, almost unchanged in wave length, is turned aside from the direct beam, and scattered in practically all directions; (2) another part is absorbed, i. e., changed almost entirely into heat energy; (3) the remainder is propagated unchanged in wave length.

An exact mathematical theory has been formulated for the general nonselective scattering (molecular diffraction) by the permanent gases of the atmosphere, from which the transmission coefficients, sky illumination and sky color may be deduced; [12] but the nonselective scattering associated with water vapor exhibits anomalies. Selective absorption by water vapor, carbon dioxide, ozone, and oxygen, and the effects of dust and other foreign material in the air are difficult to treat theoretically, but have been extensively investigated by observation and experiment. (See fig. 21.)

From the known intensity distribution of solar radiation outside the atmosphere,[11] the distribution of insolation at the surface of the earth could be computed if the transmission of the atmosphere could be determined. In general, only the part of the transmission coefficient depending on molecular scattering by the permanent gases can be calculated with certainty from physical theory. The depletion from scattering and absorption by water vapor, and the effects of dust, etc., may be obtained more or less accurately from relations that have been established by observation, but in practice the distribution of water vapor and dust throughout the depth of the atmosphere and their variations with time are not usually known with any completeness. Estimates of the radiation receipt that may be expected from sun and sky at a given locality may be made when climatological data are available, especially if there is a pyrheliometric station in the same general region, but they are inevitably subject to considerable uncertainty; only direct observations can provide reliable values of the radiant energy actually received (*cf.* Mo. Wea. Rev., 62: 282, 1934).

### INSOLATION AT THE SURFACE OF THE EARTH

The solar radiation observational program conducted by the Weather Bureau has been devoted principally to regular pyrheliometric measurements of the intensity of solar radiation at normal incidence, and to continuous registration of the total solar and sky radiation that is received on a horizontal surface. Occasional measurements of sky polarization are included. The determination of atmospheric water vapor content and turbidity is also now a regular part of the observations. Summaries of all these data are published monthly in the Review. Registrations of the visible component and of the ultraviolet component have recently been initiated at the Washington, D. C., station. From time to time, photometric and nocturnal radiation measurements have been conducted; and various miscellaneous studies, such as investigations of atmospheric dust, have been made. A number of summaries of the data obtained, together with several extended investigations based on these data and pertaining both to theoretical meteorology and to practical problems, have appeared in the Monthly Weather Review and elsewhere during the past 20 years:

General introductory summaries of the subject as a whole are provided by H. H. Kimball, Solar Radiation and its Role (ch. 3 of *Physics of the Earth—III: Meteorology*, National Research Council Bulletin 79, Washington 1931); H. H. Kimball, Solar Radiation as a meteorological factor, *Reviews of Modern Physics*, 4: 259–277, 1932, and Mo. Wea. Rev., 59: 472–479, 1931; H. H. Kimball and I. F. Hand, Intensity of solar radiation as received at the surface of the earth (in Nat. Res. Counc., *Biological Effects of Radiation*, pp. 211–226, New York, 1936), abst. in Mo. Wea. Rev., 63: 1–4, 1935; H. H. Kimball, Amount of solar radiation that reaches the surface of the earth on land and sea, Mo. Wea. Rev., 56: 393–399, 1928. (See also U. S. Weather Bureau, *Circular Q*, Pyrheliometers and Pyrheliometric measurements.) A brief account of the general principles of pyrheliometry is given by Kimball, *Bull. Mt. Weath. Obs.*, 3: 72–85, 1910.

Pyrheliometric measurements in most countries are reduced to the Smithsonian Scale of Pyrheliometry of 1913 (C. G. Abbot and L. B. Aldrich, Smithsonian Pyrheliometry Revised, *Smith. Misc. Coll.*, Vol. 60, No. 18, 1913). The Angström compensation pyrheliometer,[13] adopted as the standard by the Meteorological Conference at Innsbruck in 1906 and later in the same year by the Solar Physics Union at Oxford, is still accepted as the standard by a few countries in the Eastern hemisphere, although in many instances the ratio, "Smithsonian Standard/Angström Standard=1.035" has been applied to convert

[10] See *Annals* of the Astrophysical Observatory of the Smithsonian Institution, vols. 1–5. Washington, 1900–1932.

[11] See A. Angot, Recherches théoriques sur la distribution de la chaleur à la surface du globe, *Ann. Bur. Cent. Mét.*, mémoires de 1883, Paris, 1885. Wm. Ferrel, Temperature of the Atmosphere and Earth's Surface, *Prof. Papers of the Signal Service*, No. XIII, 1884. M. Milankovitch, *Théorie mathématique des phénomènes thermiques produits par la radiation solaire*, Paris, 1920. F. Baur und H. Philipps, *Gerlands Beiträge zur Geophysik*, 42: 160–207, 1934. *Cf.* W. J. Humphreys, *Physics of the Air*, 2d ed., pp. 78–84; *Smith. Met. Tables*, 5 ed., tables 98–99. See curve 1 in fig. 20.

[12] See W. J. Humphreys, *Physics of the Air*, 2 ed., pp. 537–546; L. V. King, On the scattering and absorption of light in gaseous media, with applications to the intensity of sky radiation, *Phil. Trans.*, A212: 375–434, 1913. F. E. Fowle, The atmospheric scattering of light. *Smith. Misc. Coll.*, Vol. 69, No. 3, 1918.

[13] Knut Ångström. The Absolute Determination of the Radiation of Heat with the Electric Compensation Pyrheliometer, and Examples of the Application of this Instrument. *Astrophys. Jour.*, 9: 332–346, 1899.

Ångström measurements to the Smithsonian scale.[14] In 1934, the Smithsonian Institution announced [15] that recent standardization tests lead to the conclusion that their former scale of pyrheliometry is about 2.3 percent high. Because of the great mass of pyrheliometric data that have been accumulated, it has been thought best to adhere to common practice and continue the use of the former scale; this has been done in the case of all pyrheliometric values herewith. The question of standard pyrheliometric scales is still under investigation by the International Meteorological Committee.

*One gram calorie per square centimeter per minute* is the unit in general use for nearly all pyrheliometric work. For the convenience of engineers and others who may wish to convert to other units, the following equivalents are given:

$$1 \text{ g. cal.} = 0.0039685 \text{ B. T. U.} = 4.186 \text{ joules}$$
$$= 3.0874 \text{ ft. lb.} = 0.42685 \text{ kg m}$$
$$= 1.5593 \times 10^{-6} \text{ HP. hour} = 0.0011628 \text{ watt-hours}$$

During an average clear day in midsummer at Washington, D. C., about 1,000 kilowatt-hours of solar energy is received on each square dekameter—about the area occupied by an average eight-room house. Yet only 1 part in 2,200 million of the total energy radiated from the sun is intercepted by the entire earth.

### *Pyrheliometric Stations*

The number of pyrheliometric stations is gradually increasing, not only in the United States but also throughout the world. In 1927–30, a list of pyrheliometric stations over the globe, with a bibliography of available data and a summary of the measurements, was compiled by Kimball.[16]

Table 1 gives information about the solar radiation stations which are maintained by, or cooperate with, the Weather Bureau. (See fig. 1.) A station at Athens, Ga., is also in prospect.

American University is about 3 miles northwest of the Central Office of the Weather Bureau in Washington, 5½ miles northwest of the United States Capitol and 1½ miles northwest of the Naval Observatory. There are no manufacturing plants within 3 miles of the University, but suburban development has gradually increased atmospheric pollution by smoke. During recent years, the rapid growth of trees close to the observing station has interfered to a slight extent with normal-incidence measurements at low solar altitudes; otherwise the site is considered as good as could be obtained within the District of Columbia, chiefly because of its high elevation and its location in the windward quarter of the city.

At Madison, Wis., the pyrheliometer is mounted on top of the instrument shelter on the roof of North Hall, University of Wisconsin, which is located on a bluff a short distance from the south shore of Lake Mendota. Most of the manufacturing establishments are in the eastern part of the city, but some contamination results from the university heating plant and also from the rapidly growing suburban development and the railroad lines adjoining the campus.

At Lincoln, Nebr., the radiation apparatus is located on the farm campus of the State University, 2½ miles northeast of the business section of the city. With a west or northwest wind the atmosphere is very clear; but with winds from other directions, smoke from railroads and industrial plants often depletes solar radiation receipt.

Blue Hill Observatory of Harvard University is located on the highest point of a long ridge 10 miles south of Boston; and little trouble is experienced from smoke, although occasionally with a north wind a slight smoke effect from the city is noticeable.

The station at Chicago is located in Rosenwald Hall on the campus of the University of Chicago. For a large city, the instruments have excellent exposure. Although smoke is troublesome at times, considerably more radiation is received here than at the main office of the Weather Bureau in the Federal Building within the Loop.

The city of New York cooperates in the maintenance of Central Park Observatory, located at Seventy-ninth Street and Tranverse Road in the heart of the park. An ornate tower furnishes excellent exposure for the pyrheliometer; and here, as in Chicago, a comparatively free low horizon gives values representative of average large city conditions.

The pyrheliometer at Pittsburg was at first located on top of the Oliver Building, a tall skyscraper in the heart of the city. After a few years of record were obtained, the apparatus was removed to the airport in the suburbs in order to obtain the differential values between the city and its suburbs; later, this station was discontinued.

The station at Fairbanks, Alaska, latitude 64° 52′ N., is much the farthest north at which total solar and sky radiation measurements are made regularly. The nearest approach to it is the Union of Soviet Socialist Republics station at Sloutzk, latitude 59° 41′ N. A few observations of this character have been made in the past at Green Harbor, Svalbard, latitude 78° 00′ N.[17] The pyrheliometer at Fairbanks was mounted on a support 10 feet above the roof of the office building, and has an unobstructed exposure to the horizon in all directions.

The pyrheliometric station at San Juan, P. R., is the farthest south of any of the Weather Bureau stations. Here also the pyrheliometer is located on top of the building in which the Weather Bureau has its offices; and it has a good exposure, comparatively free from shading effects of nearby objects. Here cooperation exists between the Weather Bureau and the director of a medical research project carried on under the auspices of Columbia University.

The Mount Washington station, opened in December 1933, was maintained for a brief period through the cooperation of Harvard University. It had the highest elevation of any of the stations. However, the difficulties of maintaining pyrheliometric apparatus on this peak were so great that after intermittent records were obtained for a few months, the attempt was abandoned. Lightning and wind destroyed pyrheliometers in rapid succession.[18]

Of all the pyrheliometric stations from which records are now regularly tabulated in the REVIEW, the one maintained by the Bureau of Entomology at Twin Falls, Idaho, has the greatest altitude, 1,300 meters.

At Tulane University in New Orleans, the pyrheliometer is mounted on a platform 40 feet above sea level; it measures all the direct solar radiation except when the sun is very low, but considerable sky radiation fails to record because of the presence of nearby buildings and trees above the horizon line. The hourly values are therefore reduced by a small but known amount.

At the Scripps Institution of Oceanography, La Jolla, Calif., the Weather Bureau type of thermoelectric pyrheliometer first in use gradually became defective. The recorded values during the deterioration period gradually decreased; and because of the impracticability of determining with accuracy the true values of radiation during that period, a new set of normals has been started with September 1935, which include only the values obtained since the installation of a new hermetically sealed pyrheliometer. This instrument is mounted on top of a water tank, where it has free exposure to both the sun and sky, except for hills in the East which cut off early morning direct radiation from the sun; however, early morning fogs prevail in this immediate section at certain seasons of the year.

For some years, the University of Florida, located at Gainesville, furnished data. A Moll thermopile [24] recording on a Richárd microammeter provided the records; both instruments had been calibrated by the Weather Bureau. Only meager information is available concerning the exposure, except that it is known the receiving unit had a comparatively free horizon.

Special stations have also been temporarily occupied from time to time; see, e. g., H. H. Kimball, Observations on the increase of insolation with elevation, *Bull. Mt. Weath. Obs.*, 6: 107–110, 1914.

The radiation normals at a given station that is free from local influences, such as city smoke, are probably fairly representative for similar altitudes above sea level in the same general region. The observations from the preceding stations may therefore be used, together with

[14] Dorno. Tägliche, jährliche und säkulare Schwankungen der Sonnenstrahlung in Davos. (Rapport fait à la 1re Conférence internationale de la Lumière, Lausanne-Leysin, 10–13. Sept. 1928.) *Cf.* MO. WEA. REV., 47: 798–799, 1919.

[15] C. G. Abbot and L. B. Aldrich. The Standard Scale of Solar Radiation. *Smith. Misc. Coll.*, Vol. 92, No. 13, 1934.

[16] H. H. Kimball, Measurements of Solar Radiation Intensity and Determinations of its Depletion by the Atmosphere with Bibliography of Pyrheliometric Measurements, MO. WEA. REV., 55: 155–169, 1927; Measurements of solar radiation intensity and determinations of its depletion by the atmosphere, MO. WEA. REV., 58: 43–52, 1930. Observations in Arctic regions are summarized by Kimball in Gerlands *Beiträge zur Geophysik*, 32: 100–105, 1931, and MO. WEA. REV., 59: 154–157, 1931. From such observations as were available at marine stations, and from data on climatological conditions, Kimball has constructed charts of probable average solar and sky radiation received over the oceans at the times of equinoxes and solstices; MO. WEA. REV., 56: 393–399, 1928, and 59: 478, 1931; *Rev. Mod. Phys.*, 4: 271–273, 1932; Nat. Res. Counc., *Physics of the Earth*—III, pp. 48–49.

[17] H. H. Kimball. Solar Radiation Intensities within the Arctic Circle. MO. WEA. REV., 59: 154–157, 1931.

[18] *Cf.* B. Haurwitz. Total Solar and Sky Radiation on Mount Washington, N. H. MO. WEA. REV., 65: 97–99, 1937.

[24] Ladislaus Gorczynski. Simple Instruments for Direct Readings of Solar Radiation Intensity from Sun and Sky. MO. WEA. REV., 54: 381–384, 1926.

climatological data, as a basis for the preparation of charts of the approximate distribution of solar radiant energy over the country; in this way, Kimball in 1919 prepared, from data then available, tables and maps for the United States of average normal incidence intensities and their variation with altitude, and of average intensities and daily totals of combined solar and sky radiation on a horizontal surface and the illumination equivalents thereof (MON. WEA. REV., 47: 769–793).

*Total Solar and Sky Radiation on a Horizontal Surface*

Instruments for measuring the total solar and sky radiation that is received on a horizontal surface should conform closely to the following specifications if the results are to be comparable with those in general obtained elsewhere:

(1) They should be sensitive to radiation of wave-lengths between 0.295$\mu$ and 2.5$\mu$. (See fig. 2.)

(2) They should be proof against wind, weather, and moisture.

(3) The receiving surfaces should remain of constant sensitivity.

(4) The receiving surfaces must be nonselective in their reaction to radiation of different wave lengths.

(5) The instrument should be so designed that the reduction of its readings to gram-calories or other units will give results comparable with measurements taken elsewhere in accordance with standard pyrheliometric practice.

(6) The readings should not be influenced by temperature variations; that is, the sensitivity should be proportional only to the amount of incident radiation.

(7) The instrument should not reradiate to the sky.

(8) The receiving surfaces should be exposed to the entire sky hemisphere.

(9) The receiving surfaces should be flat.

(10) The hemispherical cover should be flawless, and of ample size to prevent "caustics" and shadow effects from striae.

With these requirements in mind, the Weather Bureau has adopted for its present standard the Eppley thermoelectric pyrheliometer (fig. 3), a modification of the original [19] Weather Bureau type. This instrument consists of two concentric circular rings of equal area, one blackened and the other white-coated. The hot junctions of a multiple-couple thermopile of gold-palladium and platinum-rhodium alloys are attached to the lower side of the black ring, and the cold junctions are fastened to the lower side of the white ring; the differential in temperature between the two rings when radiation falls upon them then creates an e. m. f. that is very nearly proportional to the amount of radiation received. The rings are mounted horizontally in the center of a thin spherical glass-bulb which is sealed to prevent deterioration of the receiving surfaces and also to prevent moisture from condensing within. (Cf. U. S. Weather Bureau Circular Q.)

According to Stockbarger,[20] the glass used in the manufacture of Eppley pyrheliometers transmits 82 percent of the radiation at wave length 0.335 $\mu$, 58 percent at 0.314 $\mu$, and one third at 0.32 $\mu$. Some radiation of wave length

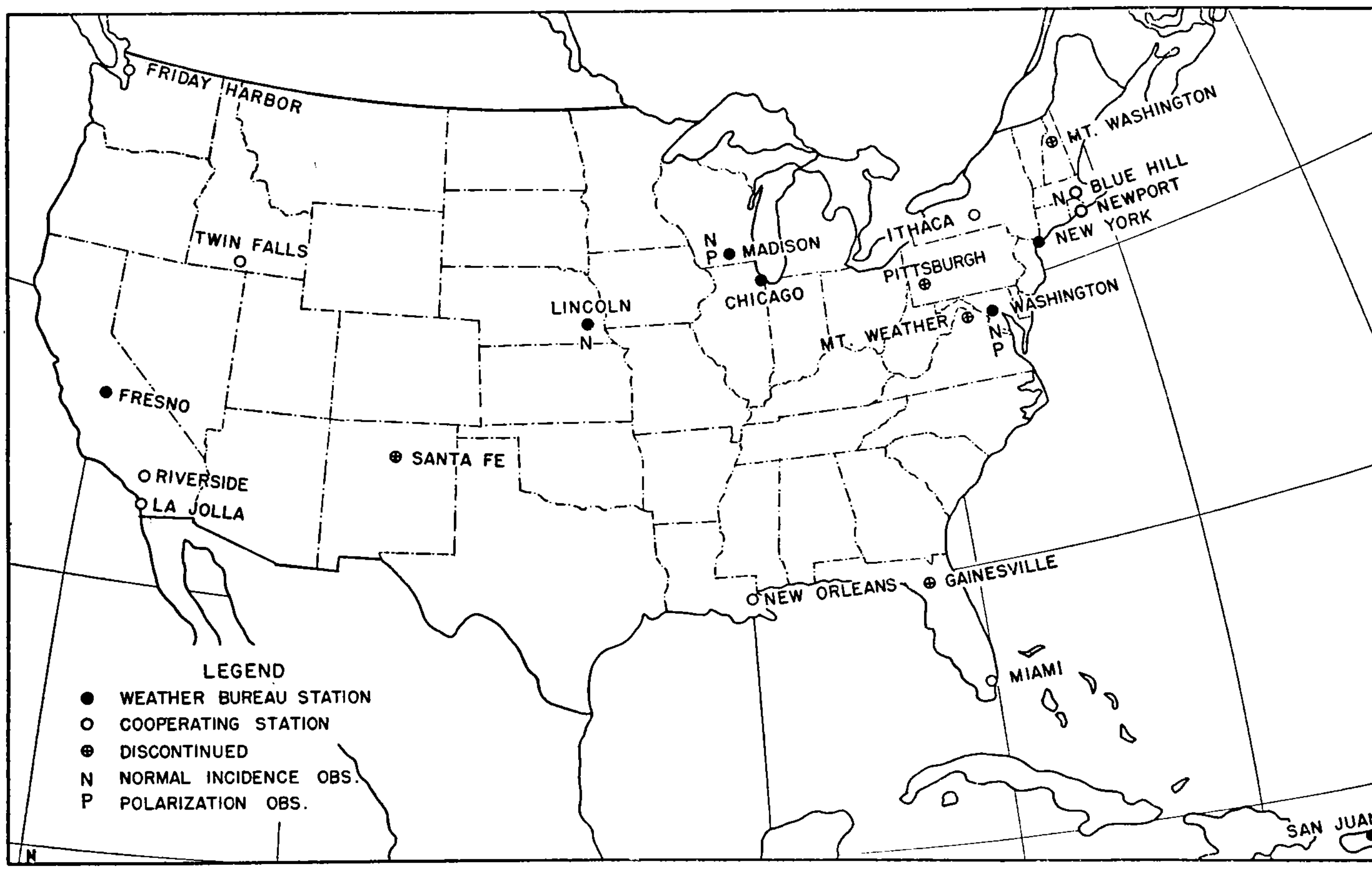



FIGURE 1.—Distribution of pyrheliometric stations in the United States (exclusive of Fairbanks, Alaska) which are maintained by, or cooperate with, the Weather Bureau. See table 1.

[19] Herbert H. Kimball and Hermann E. Hobbs, A New Form of Thermoelectric Pyrheliometer, MO. WEA. REV., 51: 239–242, 1923. Also *Jour. Opt. Soc. Amer.*, 10: 365–368, 1925.

[20] On basis of tests made at the Massachusetts Institute of Technology, Cambridge, Mass., on Eppley pyrheliometer No. 41, January 1937.

0.27 μ, considerably shorter than any received at sea level, is transmitted by this glass. The amount of radiation below 0.3 μ received in cities is negligible in records of total solar and sky radiation; it is of great importance in connection with studies of antirachitic radiation, but measurements of it must be made by other means.

In addition to the Eppley pyrheliometer, various other types of instrument also have been, and in some cases still are, in use at many stations. At Miami, e. g., the Callendar electrical resistance pyrheliometer,[21] recording on an automatic Wheatstone bridge, is used and has the advantage of a quartz cover. Experience with the older types of Callendar receivers showed that caustics and striae caused, respectively, by internal reflection and flaws in the cover, were the source of some inaccuracies.[22]

meters [23] (fig. 4), that have a full-scale deflection of either 15 or 30 microamperes. Tulane University uses an Eppley receiver, but records the radiation with a portable Richard microammeter.[24]

At Washington, Madison, and Lincoln, the e. m. f. generated by the thermopiles is recorded on Leeds and Northrup micromax potentiometers (fig. 4), which eliminate, or at least reduce to a minimum, errors arising from free-air and other temperature fluctuations.

Hourly radiation totals are obtained from the record sheets (fig. 5), by mechanical integration of the curves with a planimeter, and multiplication by an appropriate factor to reduce to gram calories.

The current weekly averages of daily totals of solar and sky radiation on a horizontal surface at the stations listed in

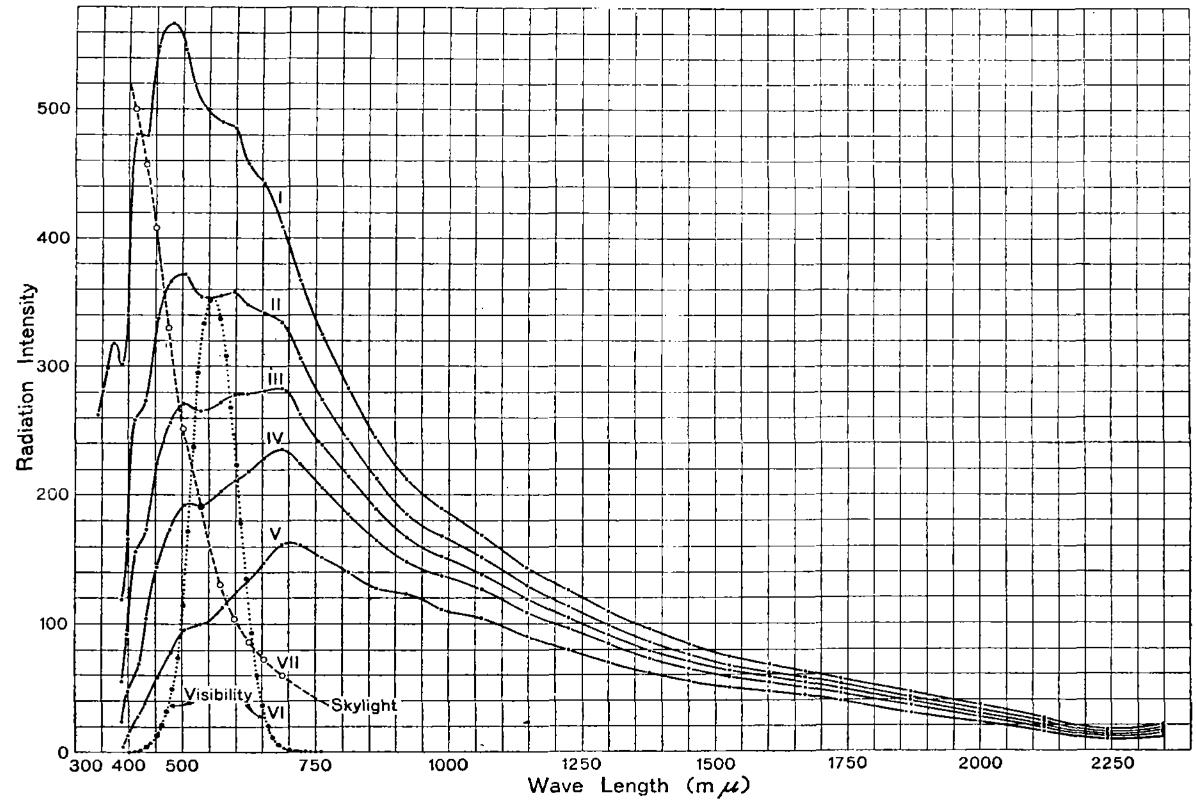



FIGURE 2.—Normal spectral energy curves of solar radiation: I, outside the atmosphere; II, air mass 1.1 (zenith distance, $z=25°$); III, air mass 2.0 ($z=60°$); IV, air mass 3.0 ($z=70.7°$); V, air mass 5.0 ($z=78.7°$); VI, visibility curve for solar radiation; VII, energy curve for sky light, Mount Wilson, Calif.

Tests also gave different results with different orientations of the instrument, because the surface formed by the imbedded wires and paint was not perfectly flat.

Pyrheliometers with spherical receiving surfaces have been suggested from time to time, but certain inherent difficulties of manufacture, and of interpretation of the records, have limited their use except for special purposes. They are, in fact, instruments for measuring normal incidence radiation and sky radiation simultaneously.

For the purpose of continuous registration, either recording potentiometers or microammeters may be used. Fundamentally, the potentiometric method is the more accurate, although the error in recording microammeters is reduced to a minimum by the addition of high resistance kept at a uniform temperature. At several stations Eppley pyrheliometers record on Engelhard microam-

table 1, and their departures from normal, are published each month in the MONTHLY WEATHER REVIEW. The original forms recording the values for each hour and each day at most of the stations are in the files of the Weather Bureau.

Table 2 gives the weekly and annual means for the periods of record of the daily total solar and sky radiation received on a horizontal surface at the 19 stations for which such data have been published in the REVIEW; table 3 gives the hourly means at Washington for each week and for the year. In figures 6 to 11, inclusive, are shown the daily averages for 16 stations, arranged in order of increasing latitude, together with a composite curve for all 16 stations, and curves giving daily maximum and minimum values at Washington. The influences of latitude and altitude should be noted. (See also fig. 20.)

In 1914, Kimball pointed out that in the data for Washington and Mount Weather there is evidence of a maxi-

[21] See Herbert H. Kimball, Total Radiation Received on a Horizontal Surface, MO. WEA. REV., 42: 474–487, 1914, for a description of this instrument and its calibration. *Cf.* U. S. Weather Bureau Circular Q; and *Jour. Opt. Soc. Amer.*, 10: 363–365, 1925.

[22] Eric R. Miller. Internal Reflection as a Source of Error in the Callendar Bolometric Sunshine Recorder. MO. WEA. REV., 43: 264–266, 1915.

[23] Circular Q, Weather Bureau; *Jour. Opt. Soc. Amer.*, 10: 367–368.

[24] Ladislaus Gorczyński. Simple Instruments for Direct Readings of Solar Radiation Intensity from Sun and Sky. MO. WEA. REV., 54: 381–384, 1926.

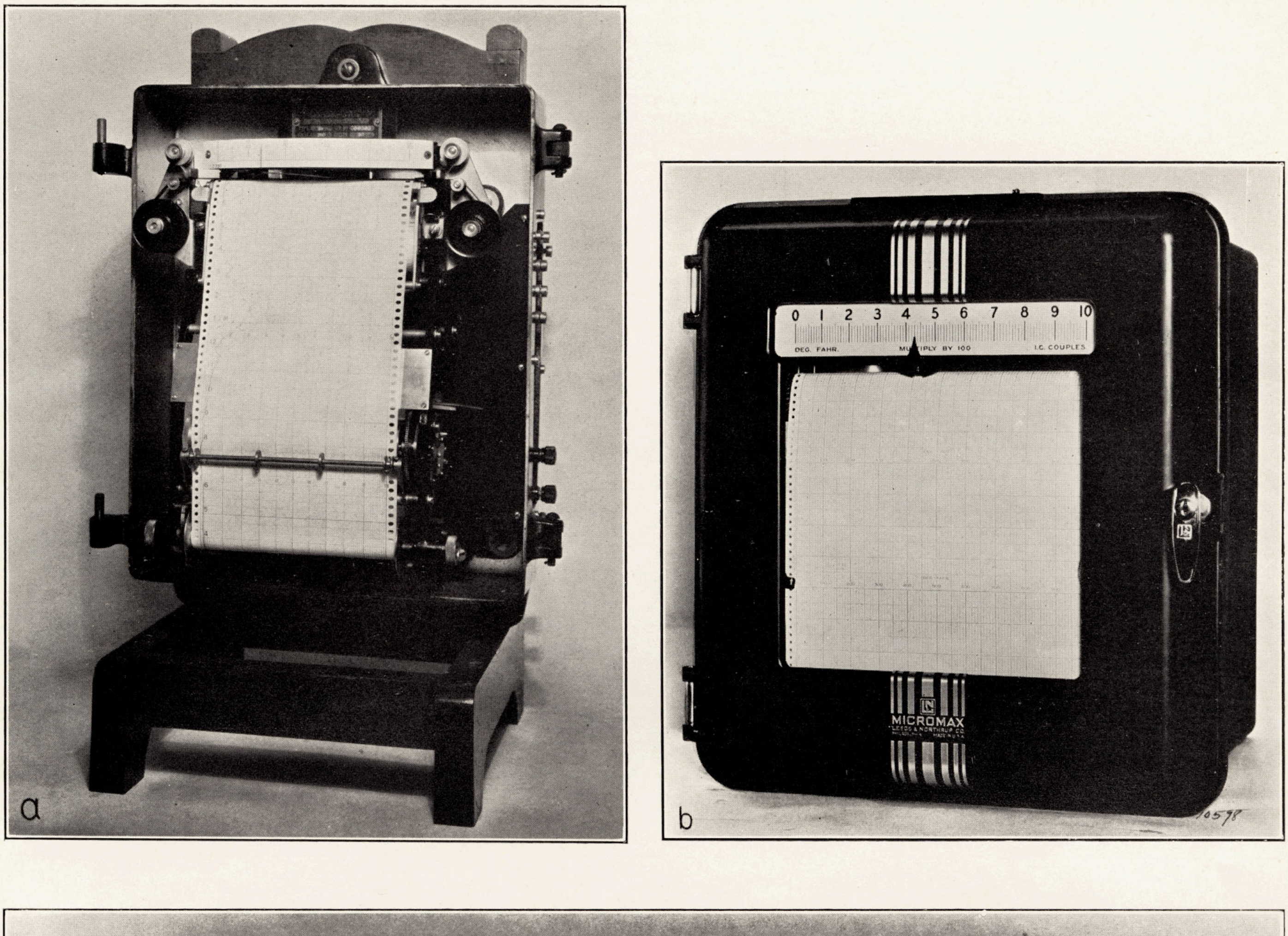
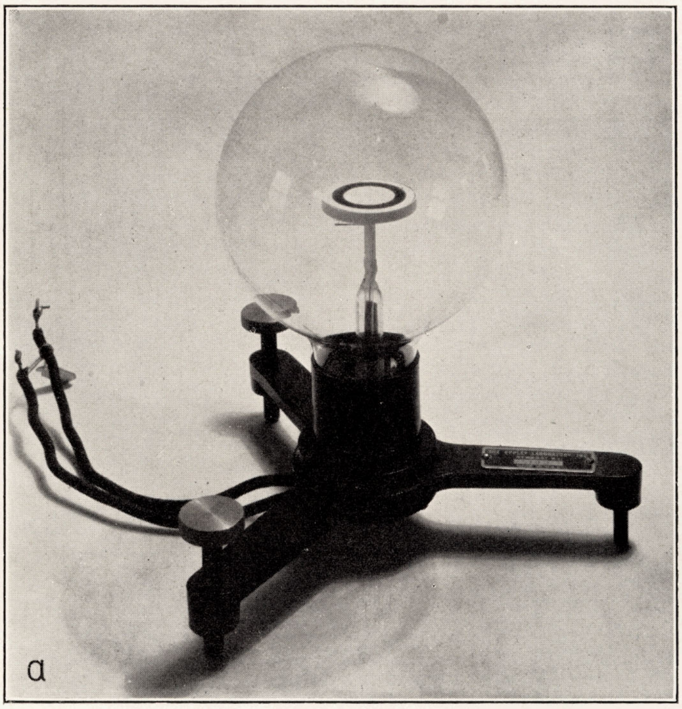



FIGURE 4.—Recorders for the thermoelectric pyrheliometer: (*a*) Engelhard recording microammeter; (*b*) and (*c*) Leeds and Northrup micromax potentiometer.



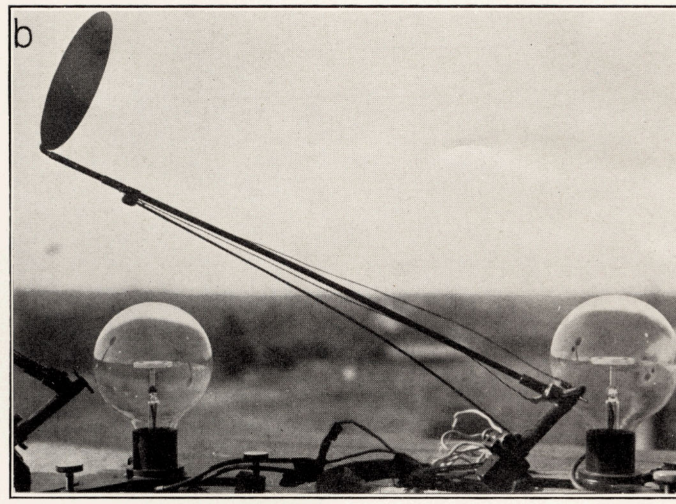




FIGURE 3.—Eppley thermoelectric pyrheliometer: (*a*) Receiving element and mounting; (*b*) occulting screen for intercepting direct solar beam.

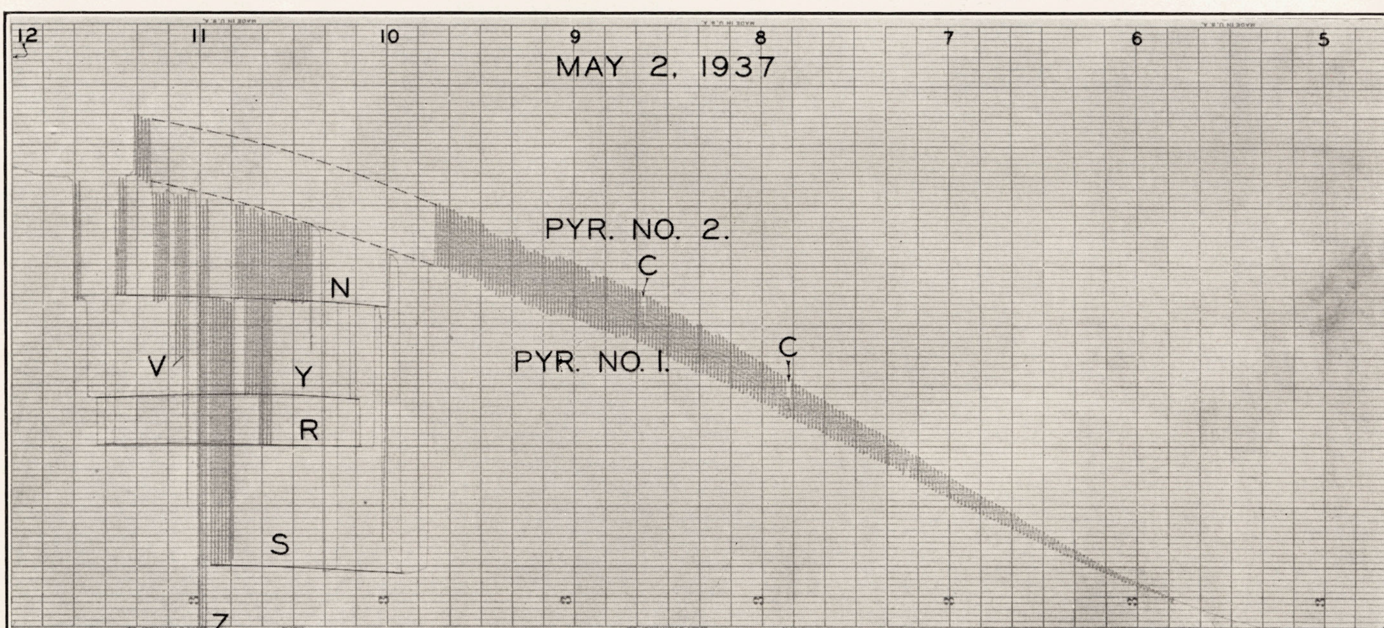



FIGURE 5.—Records of total solar and sky radiation on a horizontal surface made by two pyrheliometers operating simultaneously: The highest points on the oscillating curve are the readings of pyrheliometer No. 2, the lowest points those of pyrheliometer No. 1; instrument No. 2 was undergoing calibration. In addition, records of intensity at normal incidence, *N;* of intensity at normal incidence through color screens, *Y* and *R;* of sky radiation alone, *S;* and of the visible component alone (4,000 to 7,000 angstroms), *V,* have been taken at intervals on the same sheet. *Z* represents a check on the zero point of the vertical scale, and *C* shows irregular record made while the instrument automatically checked dry cells against a standard cell.

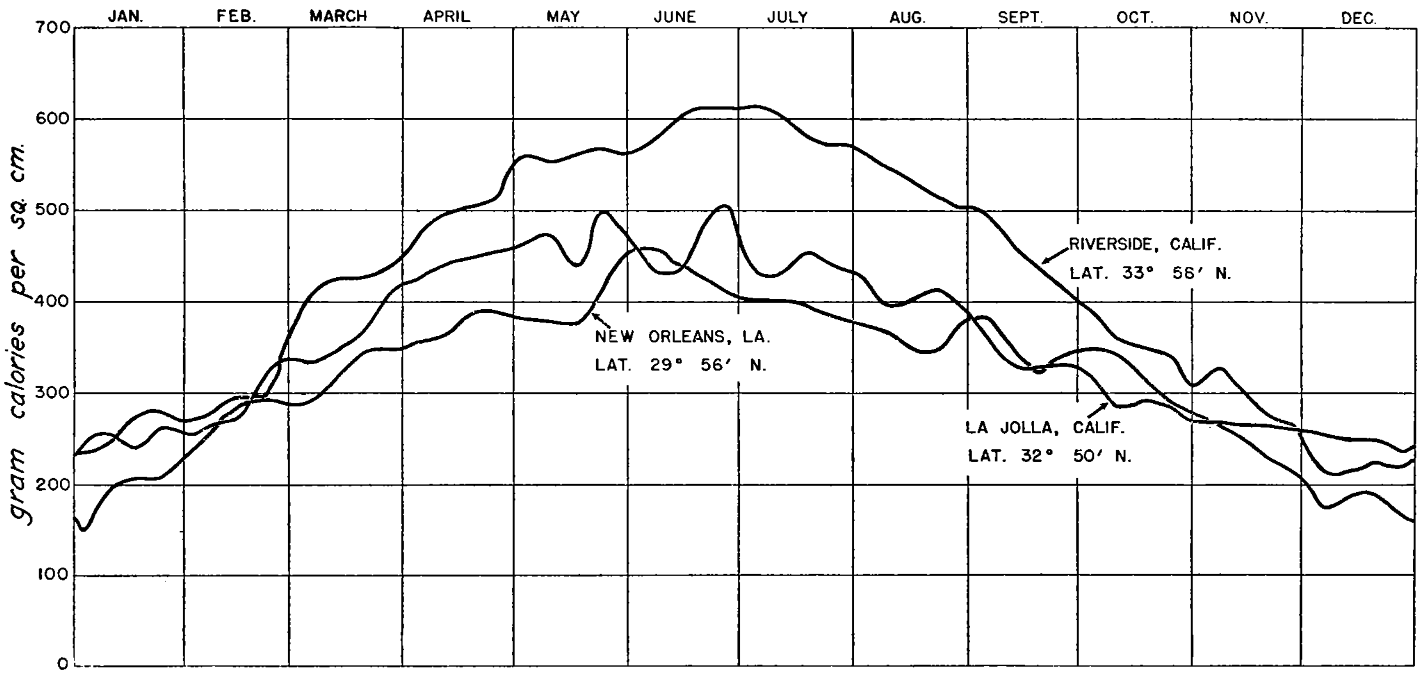



FIGURE 6.—Average daily total solar and sky radiation on a horizontal surface: New Orleans, La.; La Jolla, Calif.; and Riverside, Calif. See table 2.

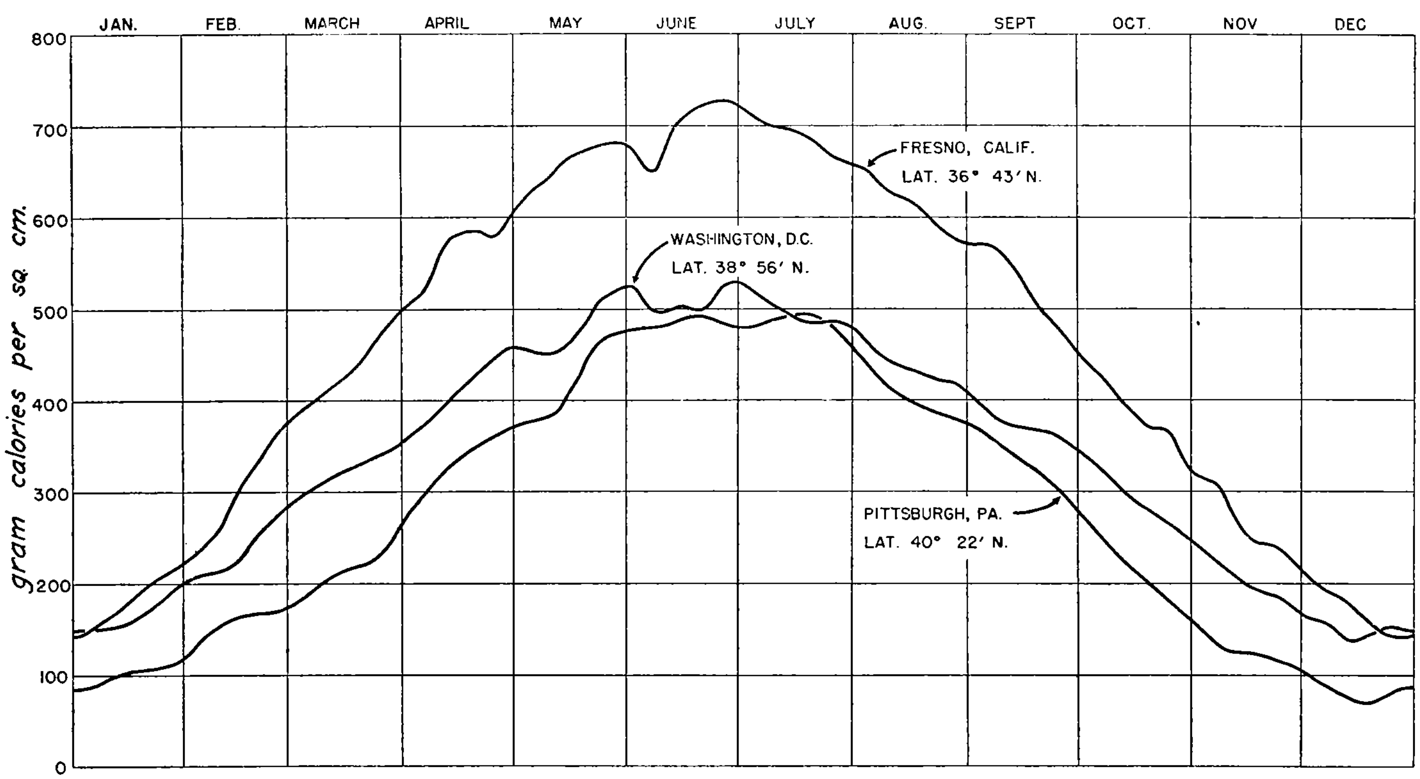



FIGURE 7.—Average daily total solar and sky radiation on a horizontal surface: Pittsburgh, Pa.; Washington, D. C.; Fresno, Calif. See table 2.

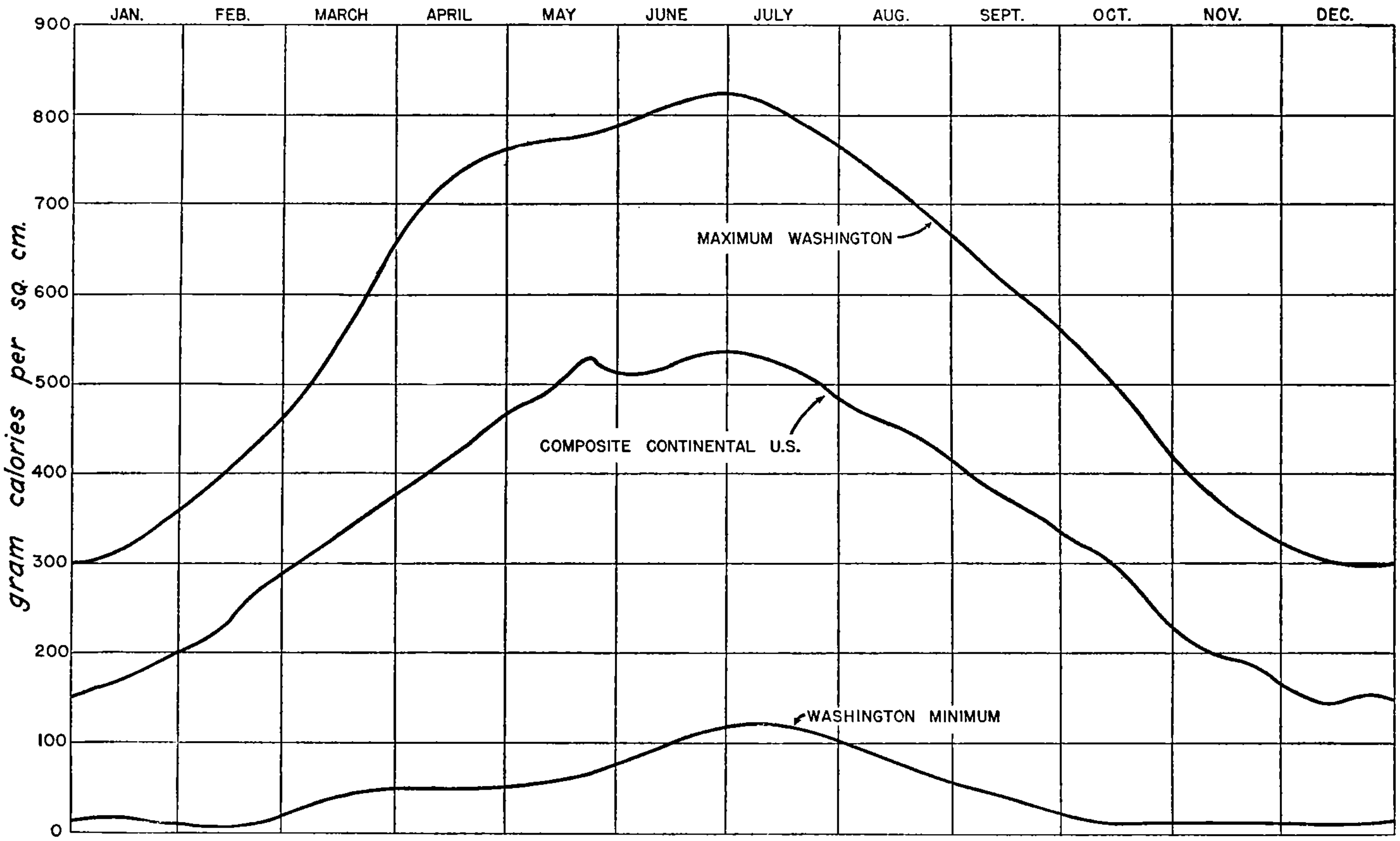



FIGURE 8.—Average daily maximum and minimum values of total solar and sky radiation on a horizontal surface, Washington, D. C.; and average values for 16 stations in the continental United States. See table 2.

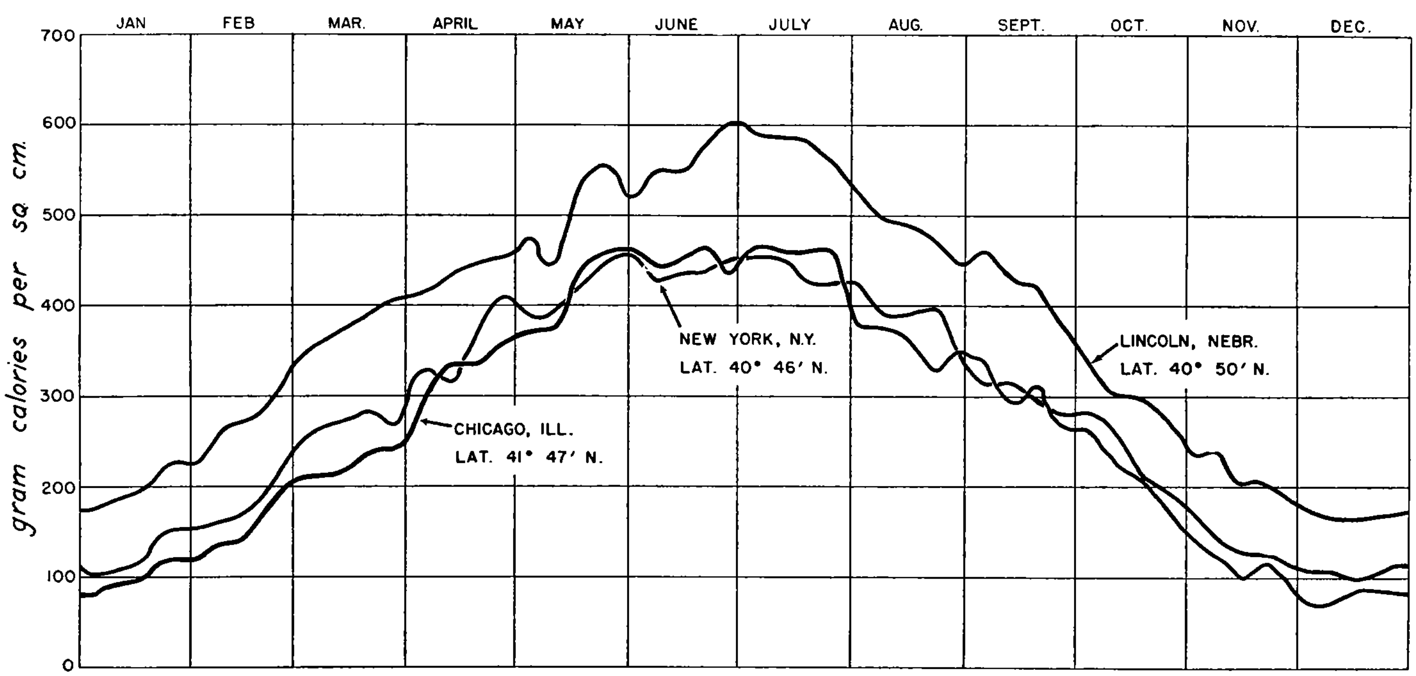



FIGURE 9.—Average daily total solar and sky radiation on a horizontal surface: Chicago, Ill.; New York, N. Y.; Lincoln, Nebr. See table 2.

mum of radiation in May, and of a secondary minimum in June or July, followed by a secondary maximum.[25] The more comprehensive data in the above curves and the last column of table 2 place the maximum at most

The difference between summer and winter values at low latitude stations is far less than at high latitude stations, because of the smaller seasonal range in the length of the day at low latitudes.

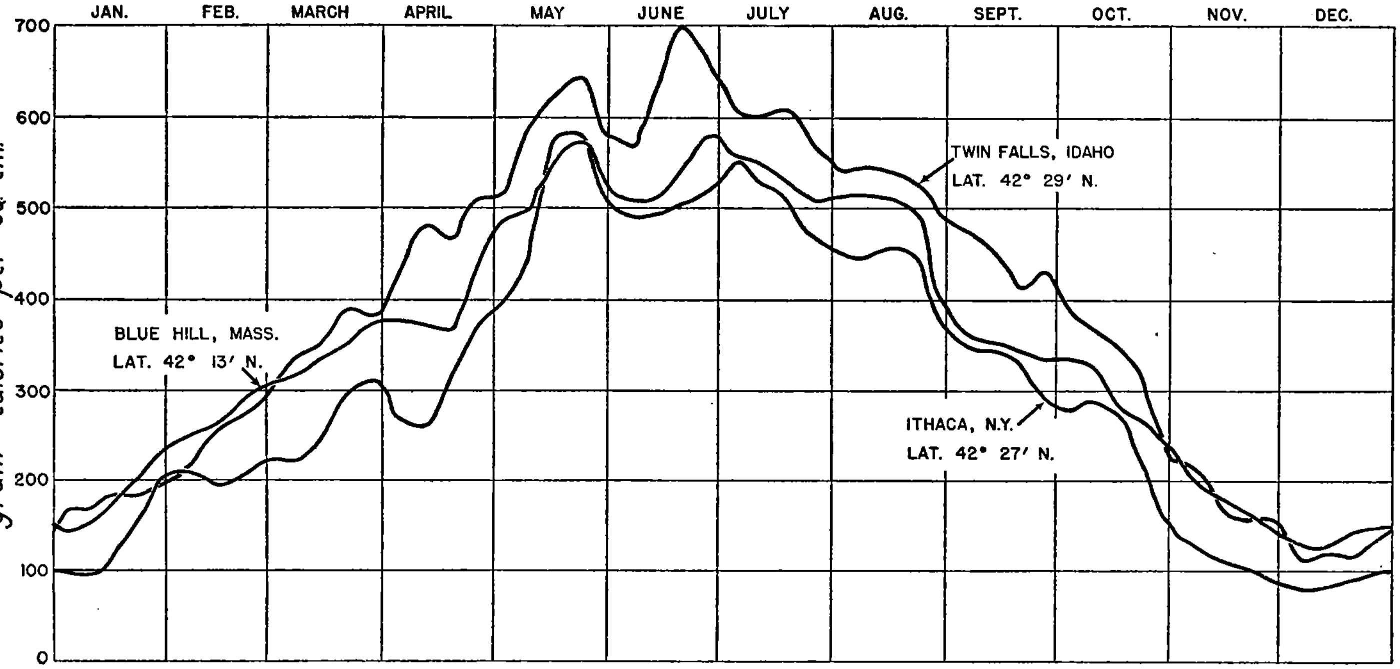



FIGURE 10.—Average daily total solar and sky radiation on a horizontal surface: Ithaca, N. Y.; Blue Hill, Mass.; Twin Falls, Idaho. See table 2.

stations during the last few days in June, with a secondary maximum shortly after the middle of May and a secondary minimum during the early part of June. The individual curves for the various stations show the secondary minima

Figure 6 shows that at Riverside, with consistently clearer skies than New Orleans, the insolation averages considerably higher than at the latter. At Riverside, the secondary minimum is during the last week in May;

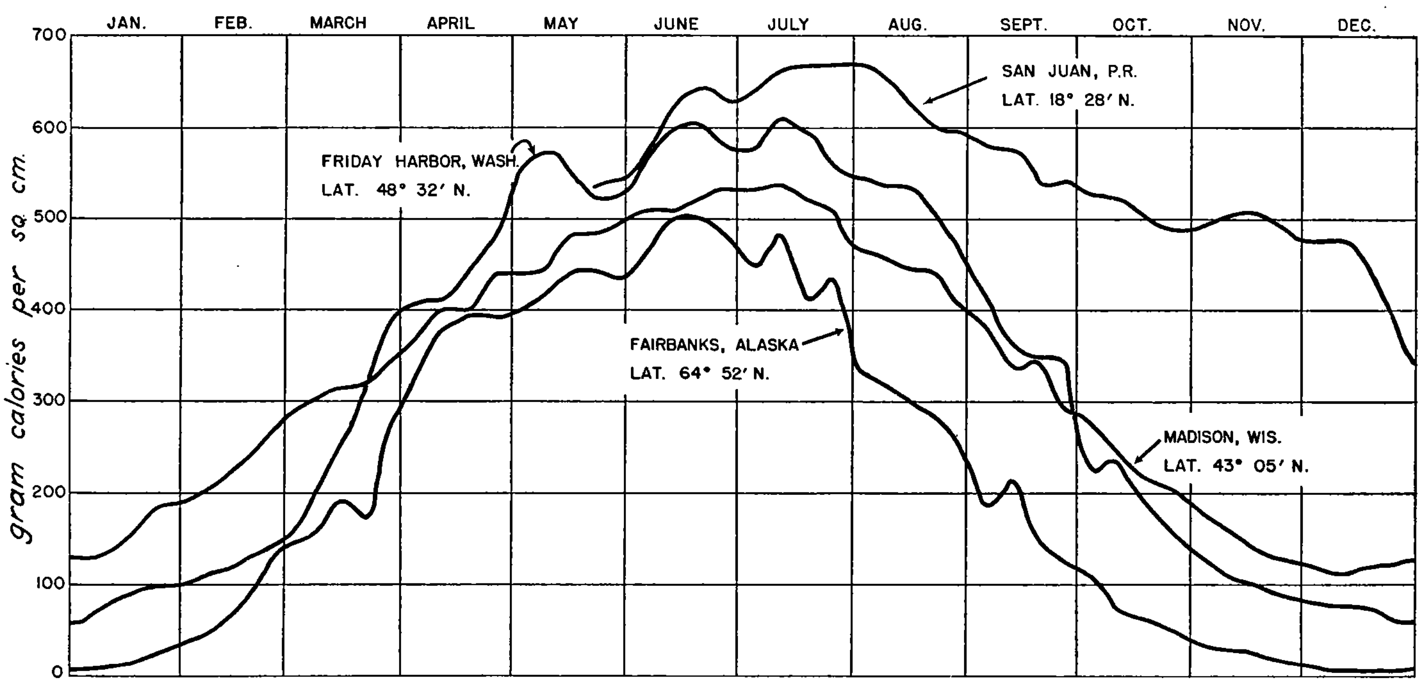



FIGURE 11.—Average daily total solar and sky radiation on a horizontal surface: Friday Harbor, Wash.; Madison, Wis.; Fairbanks, Alaska; San Juan, P. R. See table 2.

within 2 weeks of the mean, and in practically every case it is well defined; a study of the average cloudiness and average sunshine at these stations during the times of the secondary minima should prove informative.

but at New Orleans, the absolute maximum is during the first week in June. *Cf.* H. S. Mayerson and H. Laurens, *Total Solar Radiation at New Orleans*, Mo. WEA. REV., 62: 281–286, 1934.

The La Jolla data must be used with the condition of the pyrheliometer, noted above, borne in mind; sufficient

[25] Mo. WEA. REV., 43: 101, 1915.

time has not yet elapsed since the installation of a new pyrheliometer at that station to warrant publishing new normals.

The curves of maximum and minimum values at Washington (fig. 8) were drawn by interpolating between a large number of rather evenly distributed high and low values selected from all the observed values at that station. The curve of maxima shows relatively high values during early spring, with a flattening out toward the end of that season. The line is exceptionally smooth during the latter half of the year. The curve of minima has its highest point in July; the low point is in February, however, rather than in December as might be expected.

No curve has been given for the values obtained at the airport near Pittsburg, because that station was in operation less than a year; during this period, the values averaged about 25 percent higher than those previously obtained in the business section during comparable weekly periods.

The latitudes of the three stations, Lincoln, New York, and Chicago, represented on figure 9 are the same within 1°; yet at Lincoln the insolation is much higher than at the other two, because of less cloudiness and less atmospheric pollution. The secondary minimum at Lincoln falls on the last day in May, immediately preceded by a secondary maximum. A marked tertiary minimum occurs at this station on the 10th of May; and since the curve is based on more than 20 years of continuous record, considerable significance must be given to these maxima and minima. At New York the absolute maximum occurs on the last day of May, or at the same time as the summer minimum at Lincoln. During the spring in New York, the line is very wavy. At Chicago, the primary, secondary, and tertiary maxima are of about the same order of magnitude, and the summer minimum occurs at the time of the absolute maximum at Lincoln. A very marked decrease in radiation receipts begins during the latter part of July at Chicago. For the entire year, the New York values are slightly higher than those for Chicago, which is probably an effect of greater atmospheric pollution over the latter city.

All three curves in figure 10 show great variations. At Twin Falls, many of the fluctuations are probably significant; but at the other two stations, a longer record will probably smooth out the curves somewhat. The summer minimum at Twin Falls, centering around the 8th of June, is quite pronounced, as is also the absolute maximum value on June 20. The very high elevation of Twin Falls, and the freedom from city atmospheric pollution, tend to give considerably higher average radiation throughout the year than is received at either Blue Hill or Ithaca. Twin Falls also has less cloudiness than the other two cities. The rather flat absolute maximum in the middle of May at Ithaca is outstanding, while the summer minimum persists for three weeks and is followed by a weak secondary maximum the 10th of July. Ithaca also has a rather unusual dip about the 12th of April. From the 10th of May to the middle of July, the traces for Blue Hill and Ithaca are almost parallel; the absolute maximum at Blue Hill occurs the latter part of June, but is only slightly higher than the secondary maximum the 23d of May. *Cf.* B. Haurwitz, Daytime Radiation at Blue Hill Observatory in 1933, *Harvard Meteorological Studies*, No. 1, 1934.

The curves for the most northerly three stations and that for the most southerly station appear on figure 11. From less than a year's record, the curve for San Juan clearly illustrates the effect of the southerly latitude, both by the high midsummer values and by the relatively high winter values. At Fairbanks, radiation is recorded in midwinter during less than 4 hours of the day, while in midsummer the sun shines nearly 20 hours out of the 24; moreover, during the brief period when the sun does shine in midwinter, it appears just above the horizon. As a result, the midsummer means at Fairbanks are 100 times the value of the midwinter means. Probably the outstanding feature of the Fairbanks curve is the sharp drop in radiation receipt beginning the latter part of July; the rather marked dips in the curve at about the time of the equinoxes also are noteworthy. Somewhat similar effects of a high latitude are shown by the curve for Friday Harbor, but in a much less pronounced manner. Here the secondary minimum occurs during the latter part of May, preceded by a marked crest during the early part of that month.

The curve for Madison, as would be expected with 26 years of continuous record, is exceptionally smooth.

The times of absolute minima at the different stations, all close to the winter solstice, show far less variation than the times of maxima.

Figure 12, an isopleth showing the average hourly radiation received on a horizontal surface at Washington throughout the year (table 3), has been prepared from more than 50,000 observed values; the isopleth previously prepared from fewer data [25] also shows the secondary maximum in May. The corresponding isopleth for Madison [26] shows similar irregularities which many years of record have not smoothed out.

A considerable portion of the total incident solar radiation is in the form of diffuse radiation from the sky; in fact, on cloudy days all radiation necessarily is diffuse. The percentage of diffuse to total on clear days varies with the amount of dust, water vapor, and other foreign material in the atmosphere; the chief causes of proportionately high diffuse radiation are cloudiness, industrial and railroad activities, dust from any source, and low solar altitude. The radiation from the sky alone may be measured by intercepting a screen between the sun and the pyrheliometer on clear days (fig. 3).

During the calibration of thermoelectric pyrheliometers, (fig. 5), a screen is interposed about once each hour on clear days, and a series of traces representing only the sky radiation thus obtained. By interpolation, these traces may be connected with one another; and likewise the interrupted traces for total solar and sky radiation may also be joined. The difference between the two continuous curves represents the direct solar radiation on a horizontal surface; in conjunction with normal incidence measurements, the factor is determined by which the hourly integrations of the curve on the record sheet must be multiplied in order to obtain values in gram calories of the total solar and sky radiation on a horizontal surface (*cf.* U. S. Weather Bureau Circular Q, pp. 18–22).

The pyranometer,[27] an exceedingly versatile instrument, may also be used for measuring diffuse sky radiation (as well as for measuring intensities at normal incidence and for total solar and sky radiation). Ångström [28] has devised a special instrument for measuring sky radiation.

Table 4 has been prepared from a large number of diffuse radiation measurements and shows clearly the increase in the ratio of diffuse to direct solar radiation

[25] Mo. WEA. REV., 43: 101, 1915.
[26] Arthur F. Pilppo. Seventeen-Year Record of Sun and Sky Radiation at Madison, Wis. Mo. WEA. REV., 56: 501, 1928.
[27] *Smith. Misc. Coll.*, Vol. 66, Nos. 7, 11; Vol. 69, No. 9; *cf.* Vol. 72, No. 13.
[28] Anders Angström. A New Instrument for Measuring Sky Radiation. Mo. WEA. REV., 47: 795-797, 1919.

with increase in solar zenith distances (*cf.* Mo. WEA. REV., 52:475, 1924). All values are with cloudless skies; on the relation of total radiation to cloudiness, see MON. WEA. REV., 47:780, 797, and *Quar. Jour. Roy. Met. Soc.*, 50:121–126. In cities, near the times of sunrise and sunset, the diffuse radiation actually exceeds the direct solar radiation on a horizontal surface; while on high mountains the diffuse radiation becomes almost negligible except with very low sun. During the course of atmospheric dust investigations some years ago [29] the writer studied the appearance of the sky when at an altitude of about 18,000 feet, and noted that on very clear days without interference by high clouds, the zenith was almost black with a slight indigo tinge. The ring of sky close to the sun's disk was also quite dark up to the very edge of the sun, a phenomenon never seen from sea level.

many practical applications of solar radiation data. Methods of computation, and representative results, will be found, e. g., in Mo. WEA. REV., 47:781–793, 1919, and 50:622–628, 1922 (note correction in 53:448, 1925).

### *Solar Radiation at Normal Incidence*

Ordinarily, measurements of the intensity of solar radiation on a surface normal to the solar rays are made only on working days when the sky is free from clouds; occasionally they are made on dusty or smoky days, to investigate the effects of these conditions, but observations through clouds would serve no purpose.

Standard instruments for measuring solar radiation at normal incidence are equipped with tubes that insure a minimum exposure to sky radiation. The major instru-

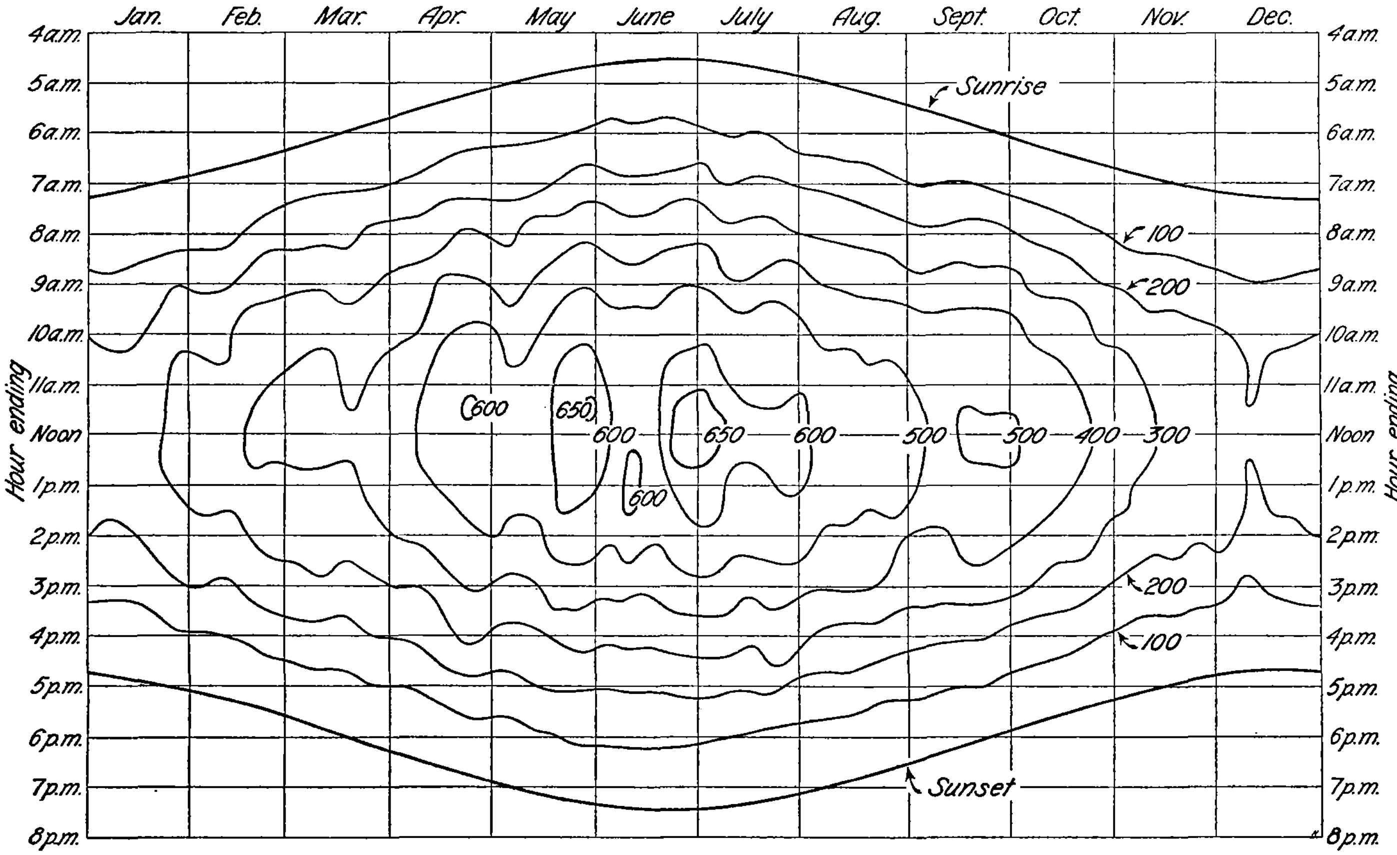



FIGURE 12.—Isopleth showing average hourly total solar and sky radiation on a horizontal surface, gram calories per square centimeter, at Washington, D. C., throughout the year. See table 3.

On January 16, 1926, the passage of a smoke-cloud over Washington at a time when there were no other clouds present, brought the total solar and sky radiation down to about 20 percent of what it would have been with a dust-free sky.[30] Shortly after the cloud passed, 2 hours later, the values resumed their normal trend. The loss of solar energy during this period was nearly 1,000,000 kilowatts per square mile; officials of the local electric power company stated that the consumption of electricity increased markedly during the passage of the cloud.

From radiation values for a horizontal surface, the values for a plane surface of any slope and orientation may be computed and are of considerable importance in

ments used by the Weather Bureau are the Marvin pyrheliometer,[31] the Smithsonian Silver Disk pyrheliometer,[32] and the thermopile; less commonly used are the Ångström pyrheliometer [13] and the pyranometer.[27]

The Marvin pyrheliometer (fig. 13), introduced in 1910, is essentially an electrical resistance thermometer; it has for its sensitive element a blackened silver disk, about 4.5 cm in diameter and 0.3 cm thick, supported on needle points, within a metal case which is inclosed in a wooden block to provide insulation. Imbedded within the silver

[29] Herbert H. Kimball and Irving F. Hand. Investigations of the Dust Content of the Atmosphere, MO. WEA. REV., 52: 133–139, 1924.

[30] Irving F. Hand, A Study of the Smoke Cloud over Washington, D. C., on January 16, 1926, MO. WEA. REV., 54: 19–20, 1926. On effects of smoke and clouds, see also MO. WEA. REV., 52: 478–479; 53: 147–148; 59: 76–77.

[13] Knut Ångström. The Absolute Determination of the Radiation of Heat with the Electric Compensation Pyrheliometer, and Examples of the Application of this Instrument. *Astrophys. Jour.*, 9: 332–346, 1899.

[27] *Smith. Misc. Coll.*, Vol. 66, Nos. 7, 11; Vol. 69, No. 9; *cf.* Vol. 72, No. 13.

[31] U. S. Weather Bureau, Circular Q, pp. 4–15. C. F. Marvin, Upon the construction of the Wheatstone Bridge for electrical resistance thermometer, *Jour. Frank. Inst.*, May 1911. Paul D. Foote, Some Characteristics of the Marvin Pyrheliometer, *Bur. Standards Sci. Paper No. 323*, 1913; MO. WEA. REV., 46: 499–500, 1918.

[32] C. G. Abbot, The Silver Disk Pyrheliometer, *Smiths. Misc. Coll.*, Vol. 56, No. 19, 1911; see also *Smiths. Misc. Coll.*, Vol. 60, No. 18, 1913, and Vol. 92, No. 13, 1934. *Cf. Annals Astrophys. Obs. Smith. Inst.*, Vol. III, pp. 47–52; *Jour. Opt. Soc. Amer.*, 10: 362–363.

block is a noninductively wound electrical resistance thermometer of insulated nickel wire in the form of a disk, of about 25 ohms resistance. During calibration, the change in resistance of this thermometer with change of temperature is carefully noted; in practice a current of known strength is passed through the coil of wire, and the change in resistance is measured by means of a specially constructed bridge and high sensitivity galvanometer.

The sensitive element is placed at the lower end of a diaphragmed tube that is equatorially mounted; and after the instrument is adjusted for declination and altitude, a clock movement keeps the receiving surface normal to the solar rays. To prevent the generation of too high a temperature, an automatic shutter opens and closes once each minute in front of the open end of the tube; a series of alternate 50-second heatings and coolings over a period of 10 consecutive minutes constitutes a standard observation. The amplitudes of the heatings and coolings progressively diminish during the series.

This instrument requires auxiliary apparatus consisting of a signal clock equipped with contacts which time the action of the relay that opens and closes the shutter; a special Wheatstone bridge; a high sensitivity galvanometer mounted on a rigid base, or preferably on a pier; and two batteries—one a 2-volt cell of constant e. m. f., and the other of 4 volts to actuate the shutter. Lead storage cells have been found most satisfactory, as their discharge rate immediately following the loss of the supercharge, or "peak," is very uniform.

Marvin pyrheliometers are first carefully calibrated in the laboratory, and then compared at frequent intervals with Smithsonian substandards which in turn are compared with the Smithsonian standard water-flow pyrheliometer.[33]

The Smithsonian pyrheliometer (fig. 14), used as a secondary standard, is one of the simplest, and yet most accurate, commonly used substandards. Requiring no auxiliary apparatus, it is well adapted to field work, although the computations necessary to reduce readings to gram-calories are tedious. A bent-tube mercurial thermometer is mounted within a silver disk, the upper side of which is blackened with a nonselective matt coating; and the whole unit is placed at the lower end of a diaphragmed tube which confines radiation to that received from the sun and from a very small ring of sky about it, and also prevents cross currents of air from blowing across the receiving surface. The disk is alternately exposed to and shielded from the sun, and the rise and fall of temperature noted. The tube is equatorially mounted, but requires manual adjustment.

This instrument is carefully calibrated against a standard waterflow pyrheliometer,[34] the primary standard, before issuance by the Smithsonian Institution, in addition to having its characteristics computed from the known properties of the elements going into its construction.

Recently, thermopiles mounted within diaphragmed tubes in much the same manner as the sensitive elements are mounted in the Marvin and Smithsonian pyrheliometers, and carefully calibrated against Smithsonian standards, have been used for continuous records of normal incidence intensity by the Blue Hill Observatory and the Weather Bureau.[35]

The Ångström pyrheliometer,[13] (fig. 24) is widely used throughout Europe; but since 1914 other instruments have replaced it for Weather Bureau purposes. The sensitive element consists of two blackened thin ribbons of manganin side by side in a nickel-plated tube with a shutter at the outer end which exposes the strips alternately to the sun; copper-constantin thermoelectric couples are attached to the backs of the strips. An electric current is passed through the shaded strip, and the amperage necessary to balance the heating of the exposed ribbon is multiplied by a factor appropriate to the particular instrument to determine the rate of radiation receipt. Because of the rectangular shape of the receiving surface, the results are vitiated somewhat more by sky radiation than in the case of instruments with circular receiving surfaces.

The Weather Bureau thermoelectric pyrheliometer,[19] when equatorially mounted, may likewise be used for normal incidence measurements.

All the measurements of the intensity of direct solar radiation at normal incidence at the stations which take such observations are published month by month in the REVIEW, with their departures from normal.

Table 5 gives the monthly mean values for the periods of record at Washington, Madison, Lincoln, and Blue Hill of (1) $I_m$, the observed solar radiation intensity at normal incidence, for different air masses[36] during the morning; (2) similar values of $I_m$ during the afternoon; (3) the average of the preceding morning and afternoon values; (4) this average reduced to mean solar distance in accordance with the annual tables of the earth's radius vector in the *American Ephemeris;* (5) the ratio of the reduced mean value to the solar constant, in percent, and (6) atmospheric transmission coefficients computed from the formula

$$a=\left(\frac{I'}{I_0}\right)^{\frac{1}{m}}, \qquad (1)$$

where $m$=air mass, $I'$=measured normal incidence intensity, and $I_0$=the mean solar constant corrected to the mean value of the radius vector for the month (if measured intensities corrected to mean solar distance, and the mean value of the solar constant $I_0=1.94$ be used, instead, the results are the same).

The data for Washington, Madison, and Lincoln are based on observations taken over a period of more than 20 years at each station, while those for Blue Hill include all observations taken there since the work was begun in 1933.

Figure 15, a graph of equation (1), has been prepared to simplify the computation of atmospheric transmission coefficients; after correction of the observed values to mean solar distance, the coefficient may be read off directly.

The above method of obtaining transmission coefficients is strictly valid only for monochromatic radiation; but the coefficients so obtained serve a useful purpose, and commonly are used to compare conditions of the sky at

[33] *Smith. Misc. Coll.*, Vol. 87, No. 15, 1932.

[34] *Ann. Astrophys. Obs. Smiths. Inst.*, II: 39–47; III: 52–72, discuss pyrheliometric standards.

[35] Herbert H. Kimball, Turbidity and Water Vapor Determinations from Solar Radiation Measurements at Blue Hill and Relations to Air Mass Types, Mo., WEA. REV., 62: 330–333, 1934; Solar Observations, MO. WEA. REV., 60: 26 and 62–63, 1932.

[36] The air mass (not to be confused with the totally different significance of this term in synoptic meteorology) is the length of the path through a homogeneous atmosphere over which the same attenuation would be produced as takes place in the actual path of the solar beam. It is approximately equal to sec $z$, where $z$ is the zenith distance of the sun; to take account of refraction, curvature of the earth, etc., Bemporad's formula

$$m=\frac{\text{atm. refr. in seconds}}{58.36\times\sin z}$$

is the most widely used, and has been employed in table 6. Other formulae have been constructed by Forbes, Bouguer, and Laplace. At some stations, and particularly at isolated points where only a few measurements are made, the height of the sun is measured directly by means of a theodolite, and near noon the secant of the sun's zenith distance used as the air mass. See *Smiths. Metl. Tables*, 5 ed., pp. lxxix and 226, 1931.

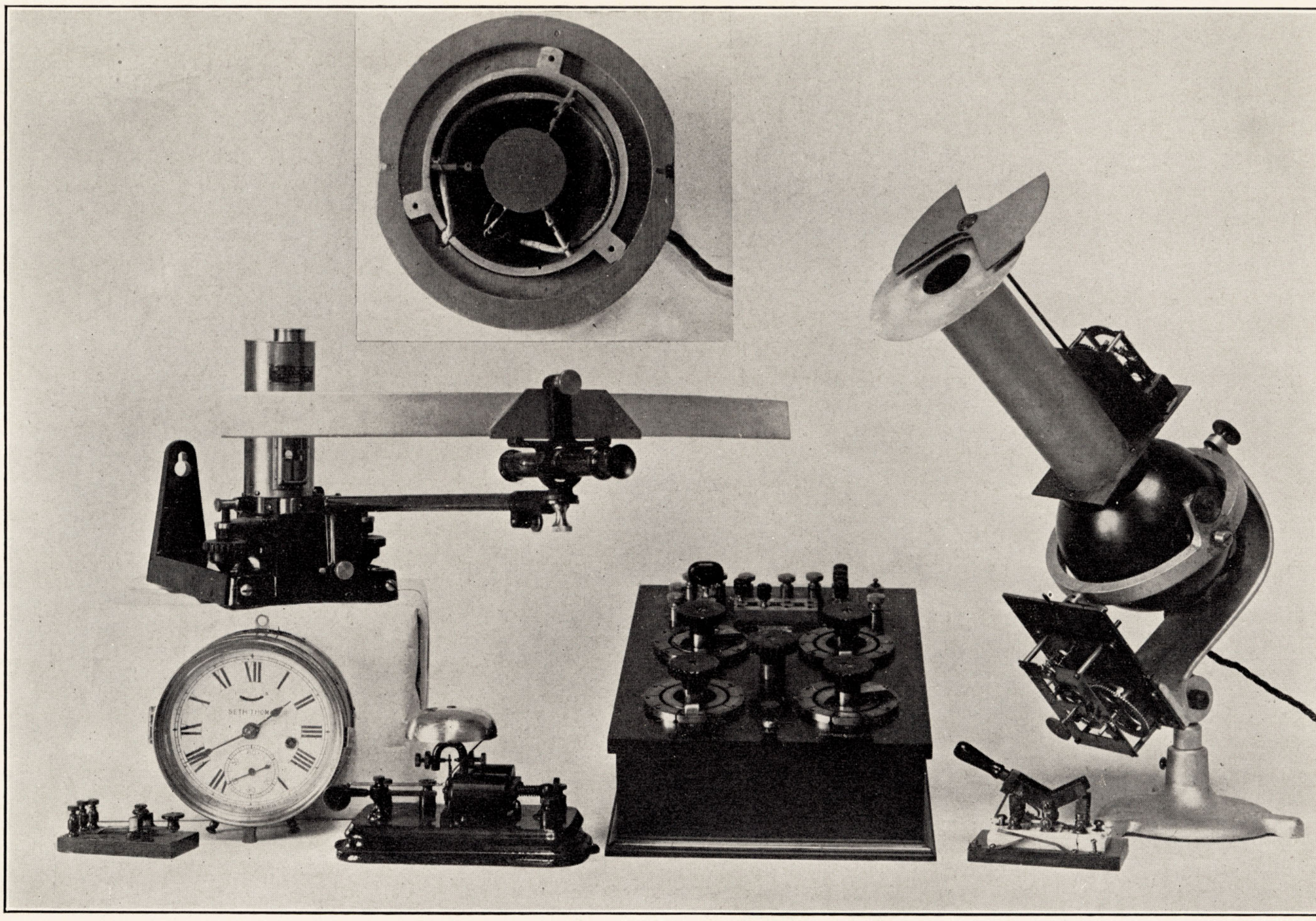


FIGURE 13.—Marvin pyrheliometer and accessories and cross section of bulb.

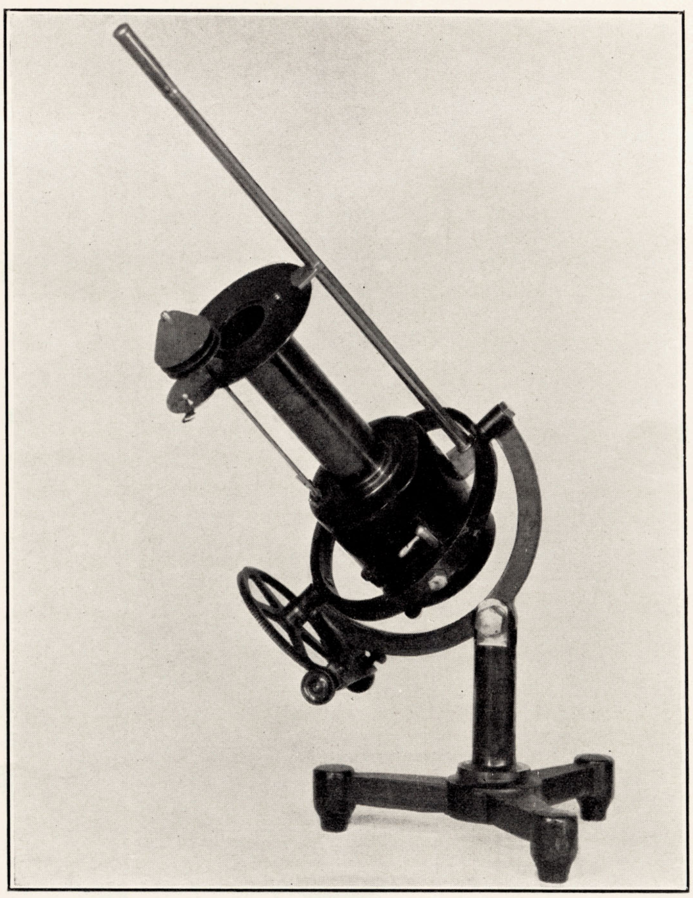


FIGURE 14.—Smithsonian silver disk pyrheliometer.

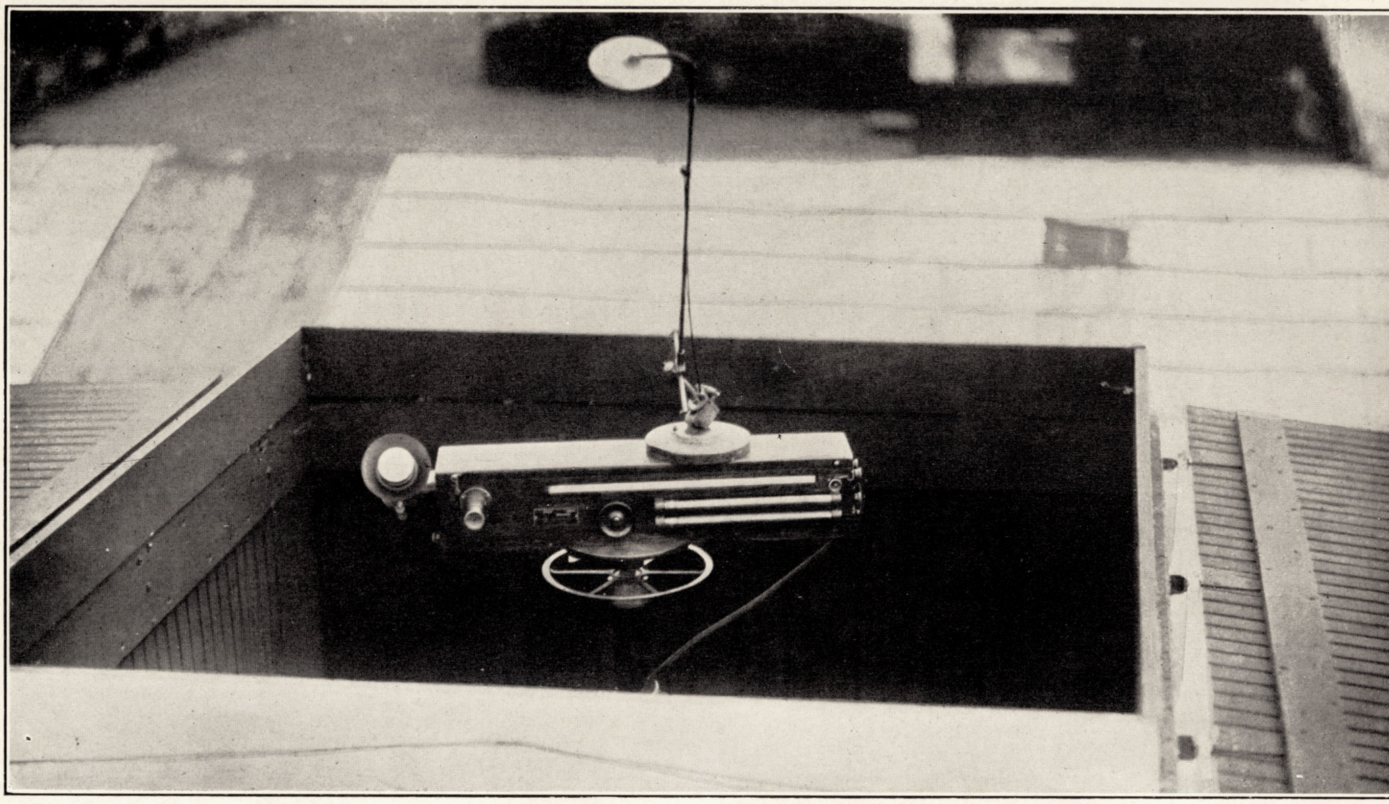


FIGURE 22.—Sharp-Millar photometer.

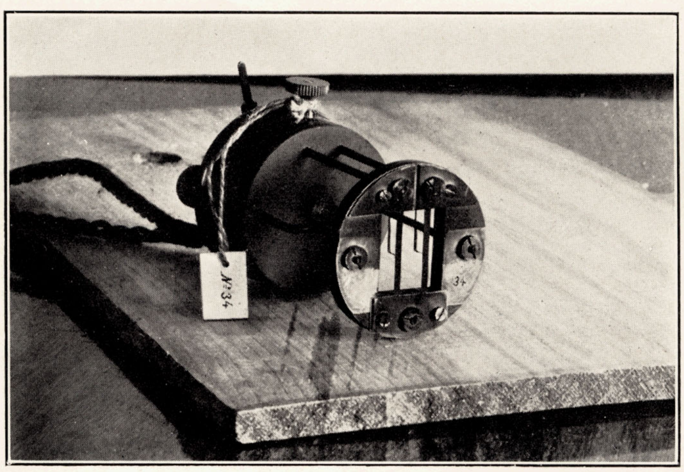



FIGURE 24.—Ångström electrical compensation pyrheliometer.

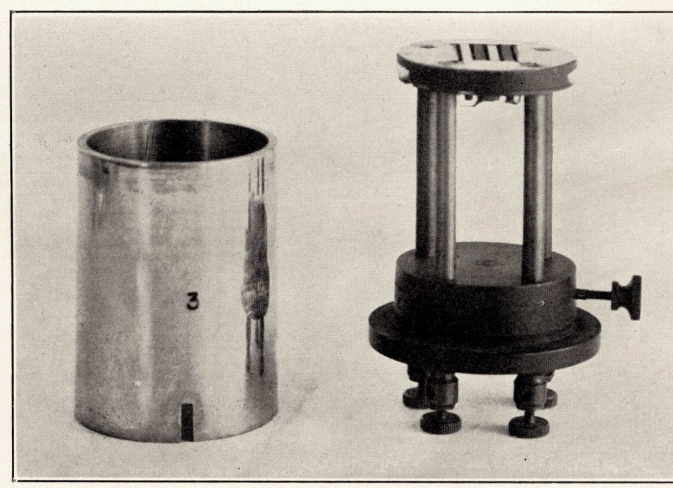



FIGURE 25.—Pyrgeometer.

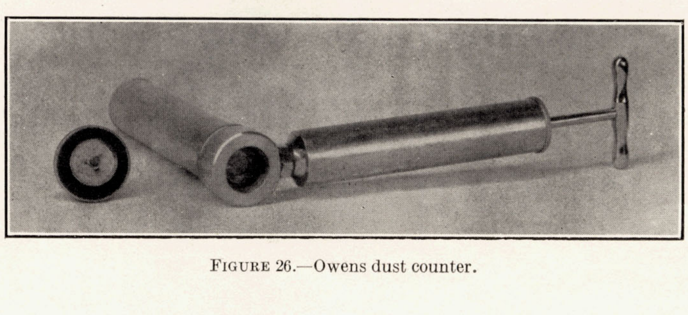


FIGURE 26.—Owens dust counter.

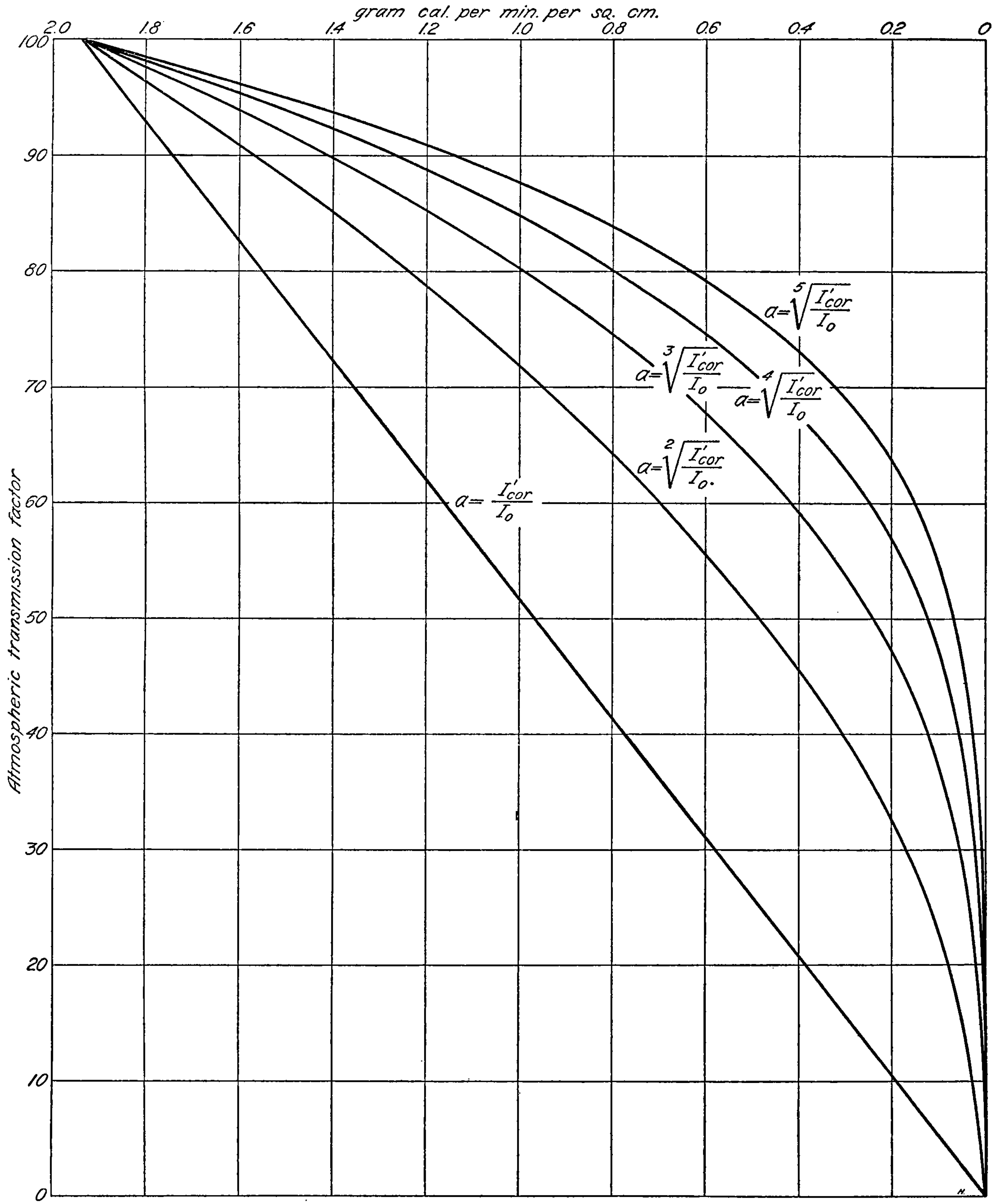



Figure 15.—Chart for calculation of atmospheric transmission coefficients by equation (1). Abscissae are intensities at normal incidence, corrected to mean solar distance.

different stations and during different months at the same station. (*Cf.* reference in footnote 26.) This method does not permit the separate effects of water vapor and dust to be evaluated. Kimball [37] has used the formula

$$a_{m-1,m}=\frac{A_m}{A_{m-1}} \tag{2}$$

to determine the atmospheric transmission coefficients, where $A_j$ is the observed intensity at air mass $j$.

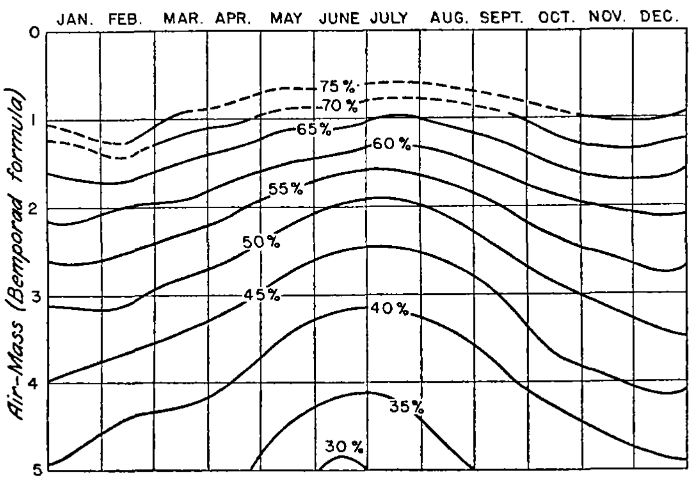



FIGURE 16.—Mean intensity of solar radiation at normal incidence, expressed as percentage of solar constant, reduced to mean solar distance: Washington, D. C. See table 5.

To better visualize the data, figures 16 to 19 have been prepared, in which are plotted the mean monthly values for different air masses at the four stations, corrected to mean solar distance and expressed as percentages of the solar constant.

The curves for Washington are rather uniform. The minimum values at air mass 5 occur the middle of June,

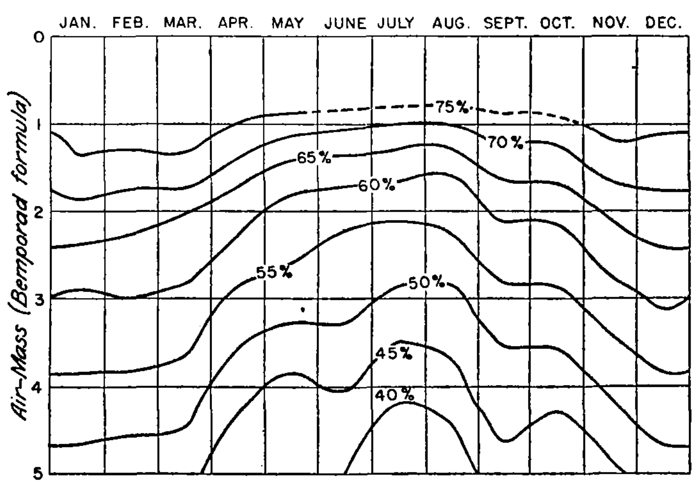



FIGURE 17.—Mean intensity of solar radiation at normal incidence, expressed as percentage of solar constant, reduced to mean solar distance: Madison, Wis. See table 5.

and at air mass 1 the middle of July; the maximum values occur at about the time of the winter solstice.

Although the longest series of observations is at Madison, the curves for this station show some remarkable irregularities. The maximum values occur at about the time of the winter solstice, while the minimum values are found from the middle of July to the early part of August. A summer maximum at the larger air masses occurs about the middle of June. The most remarkable feature, however, is the sudden decrease that begins the middle of March.

[37] Mo. Wea. Rev., 58: 45, and 55: 159.

The curves for Lincoln are somewhat more regular than those for Madison, but also show a sudden decrease beginning the middle of March.

The rather meager data as yet accumulated for Blue Hill show a number of irregularities, as is to be expected. The minimum takes place about the middle of August, with a secondary minimum at large air masses in March,

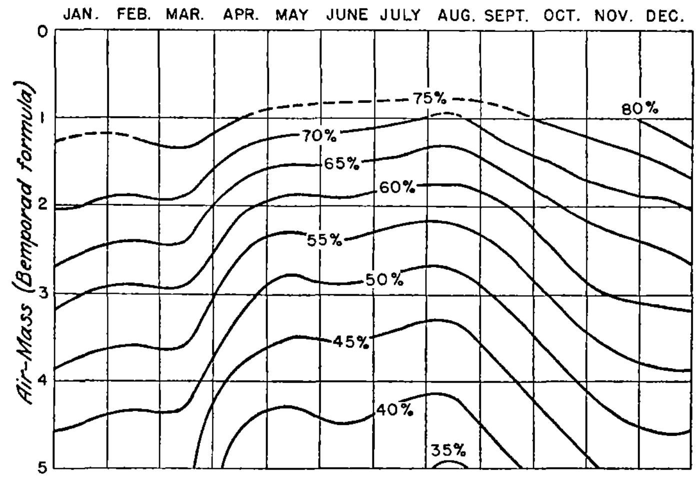



FIGURE 18.—Mean intensity of solar radiation at normal incidence, expressed as percentage of solar constant, reduced to mean solar distance: Lincoln, Nebr. See table 5.

followed immediately by a flattening out of the curves that indicates uniform atmospheric transmission during the spring instead of the marked decrease found at the midwestern stations.

Very little, if any, weight should be given the dotted extrapolations beyond air mass 1.0; they are drawn chiefly to permit ready identification of the percentage lines.

Table 7 gives both the measured and the reduced values of the maximum radiation intensities that have been ob-

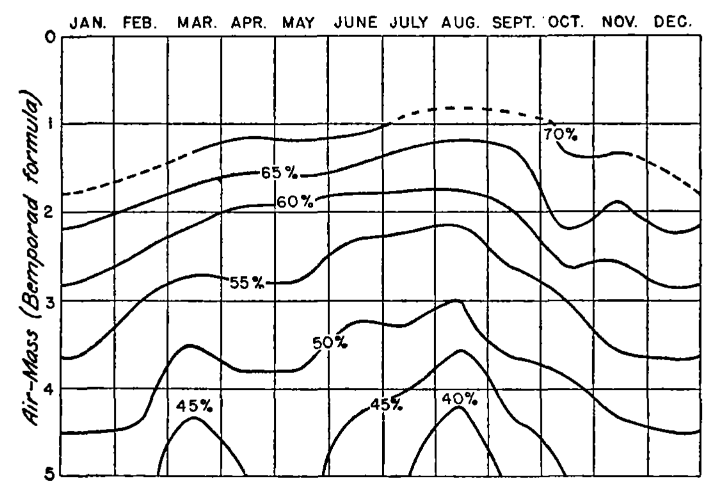



FIGURE 19.—Mean intensity of solar radiation at normal incidence, expressed as percentage of solar constant, reduced to mean solar distance: Blue Hill, Mass. See table 5.

served at Washington, Madison, Lincoln, Sante Fe,[38] and Mount Weather.[39] The values for Sante Fe average considerably higher than those for the other stations, chiefly because of the high elevation and also because the air-mass values were not corrected for this elevation. The range in monthly values is greatest at Madison and least at Mount Weather.

[38] Herbert H. Kimball. Solar Radiation Intensities at Sante Fe. Mo. Wea. Rev., 43: 590–591, 1915.

[39] Herbert H. Kimball. Solar Radiation Intensities at Mt. Weather, Va. Mo. Wea. Rev., 42: 520, 1914.

Large radiation intensities and high air temperatures do not ordinarily occur simultaneously. An especially striking illustration of this fact is provided by conditions at Washington, D. C., on February 9, 1934:[40] On that day Washington experienced the lowest temperature (−6.5° F.) since 1912; yet the highest radiation intensity ever recorded at Washington, 1.59 gr. cal. per cm$^2$ per minute, was observed at air mass 1.74 (64 percent greater than the midsummer air mass of 1.055). The atmosphere was unusually free from dust and water vapor. In fact, as a general rule winter radiation values, even after correction to mean solar distance, average higher than summer values at the same air mass. On the general relation of insolation to temperature, see Mo. Wea. Rev., 54: 417–419, 1926, and 55: 168, 1927 (*cf.* fig. 20).

The normal incidence measurements made during recent years with the thermopile[35] have been for the purpose of determining atmospheric water vapor content and turbidity, as part of an international program recommended in 1931 by the Commission on Solar Radiation of the International Geodetic and Geophysical Union (Mo. Wea. Rev., 59: 187, 1931). The so-called coefficient of turbidity is an index which expresses the depletion of solar radiation by causes other than molecular scattering in pure dry air; several such indices have been proposed, of which the one introduced by Ångström (*Geograf. Ann.*, 11: 156, 1929; 12: 130, 1930) is the one determined in this work. At wave length $\lambda$, the depletion of solar radiation at air mass $m$ by scattering alone is given by

$$I_\lambda = I_{0\lambda} e^{-(a_1+a_2)\ m} \tag{3}$$

in which $a_1$ is the coefficient of extinction from molecular scattering by pure dry air, and $a_2$ is the coefficient from scattering by water vapor and dust; in addition ot the depletion expressed by (3), there is also selective absorption by water vapor and by the other constituents of the air. Ångström finds $a_2 = \beta/\lambda^n$, in which under average conditions $n = 1.3$; $\beta$ is the turbidity coefficient.

The method for determining $\beta$ and the amount of water vapor in the atmosphere from solar radiation measurements is described in detail by H. H. Kimball and Irving F. Hand, The use of glass color screens in the study of atmospheric depletion of solar radiation, Mo. Wea. Rev., 61: 80–83, 1933; and H. H. Kimball, Determinations of atmospheric turbidity and water vapor content, Mo. Wea. Rev., 64: 1–6, 1936. The thermopile is equipped with glass color screens, mounted on the end of the tube, which do not transmit the sections of the solar spectrum

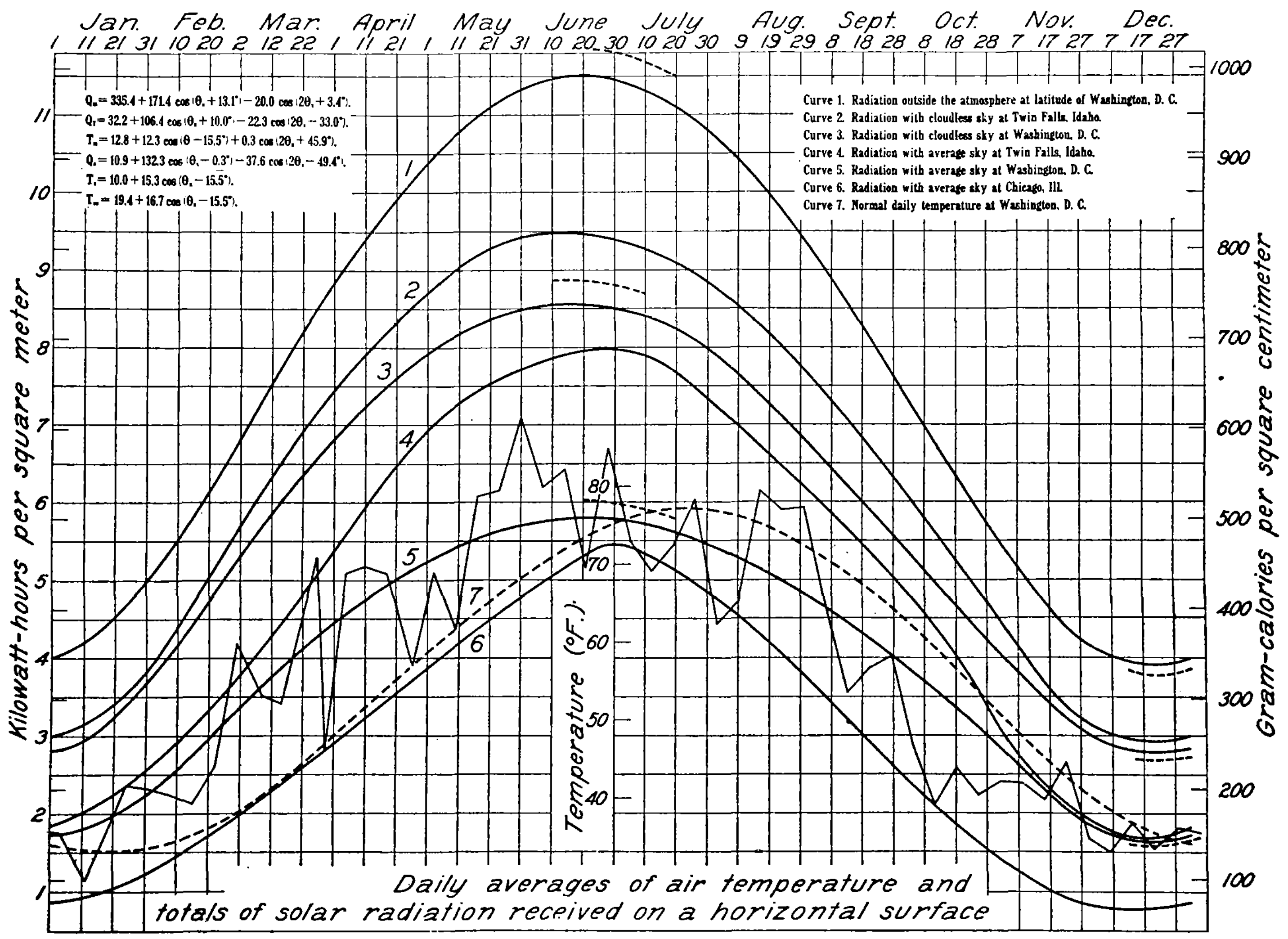



Figure 20.—Daily totals of solar radiation on a horizontal surface: The irregular solid line represents the actually observed weekly averages of total solar and sky radiation at Washington, D. C., during 1925; curves 2 to 6 are mean values. Curve 1 represents the insolation outside the atmosphere at the latitude of Washington, D. C. The short dotted segments show values reduced to mean solar distance.

[35] Herbert H. Kimball, Turbidity and Water Vapor Determinations from Solar Radiation Measurements at Blue Hill and Relations to Air Mass Types, Mo., Wea. Rev., 62: 330–333, 1934; Solar Observations, Mo. Wea. Rev., 60: 26 and 62–63, 1932.

[40] Irving F. Hand. Solar Observations. Mo. Wea. Rev., 62: 62, 1934.

that are free from important atmospheric absorption bands (*cf.* fig. 5); the measured intensity of the radiation transmitted through a color screen is corrected for reflection and absorption by the screen, including the effect of temperature (Mo. Wea. Rev., 64: 4–6; 65: 111, 195), and when the corrected value $I'$ is subtracted from the observed intensity of the total solar radiation at normal incidence $I_m$, the difference $I=I_m-I'$ represents the intensity of radiation that has been materially depleted only by *scattering* by dry air, water vapor, and dust. The depletion from scattering by dry air can be computed with the formulae developed by Rayleigh and King;[12] hence, for each of a series of assigned values for $\beta$, equation (3) can be numerically integrated over any desired obtained from charts based on relations established experimentally by Fowle (*Smiths. Misc. Coll.*, Vol. 68, No. 8) and graphically represented in figure 21 (Mo. Wea. Rev., 55: 166–168; 56: 393–394; 58: 50–52; *Smiths. Metl. Tables*, 5 ed., lxxxii–lxxxv, 239–240). The determination of $\beta$ and $w$, however, is a problem that needs further investigation; in particular, the results obtained from the methods and curves used in Europe do not seem to be consistent with those obtained from the curves used in the United States. (See Mo. Wea. Rev., 64: 377, 430, 1936; 65: 18, 62, 1937.)

The investigations of atmospheric turbidity and water vapor content are of considerable interest in connection with air mass analysis, among other things. (*Cf.* B.

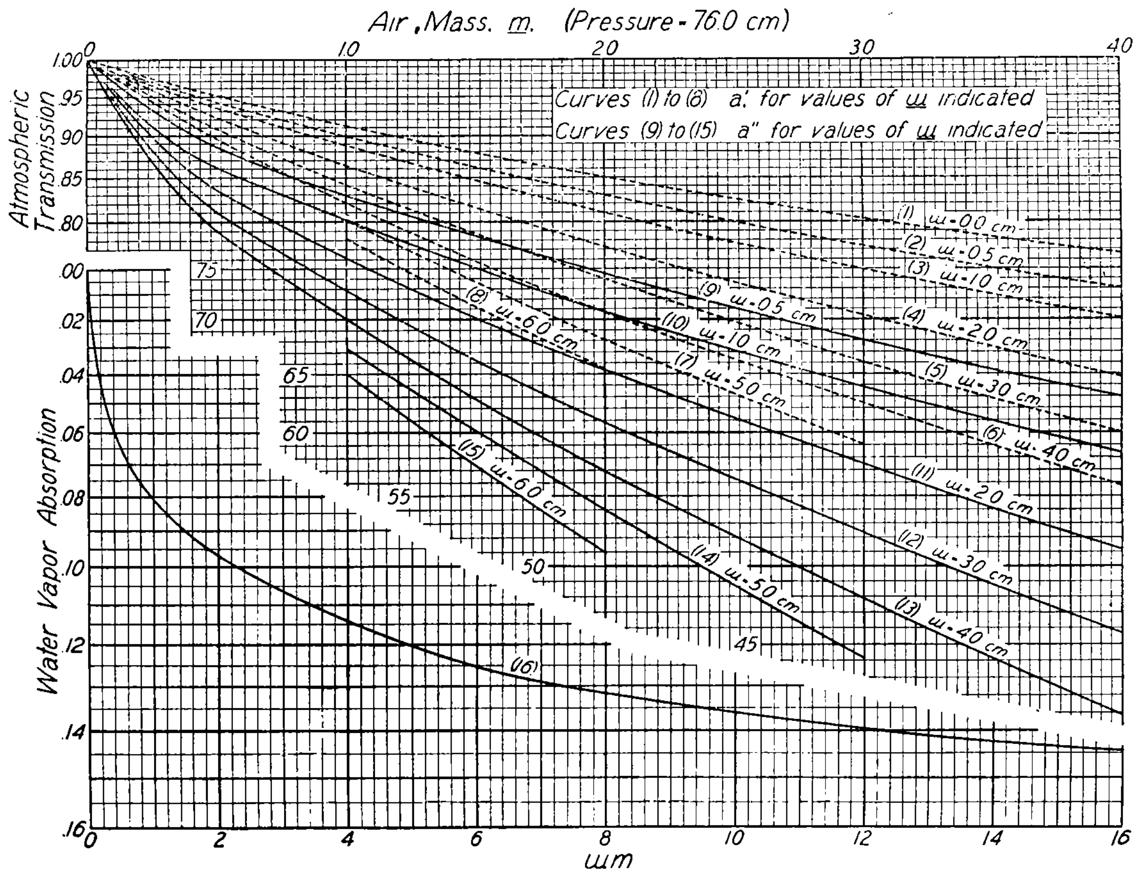



FIGURE 21.—Atmospheric transmission of solar radiation by dust-free humid air: Curves (1) to (8), inclusive, show transmission after scattering only, all selective absorption having been neglected; curve (1), for dry air, was computed from King's formulae and the Smithsonian data on spectral energy distribution of solar radiation outside the atmosphere; curves (2) to (8), for air of different humidities, were computed from Fowle's determination of the scattering associated with water vapor. Curve (16) shows depletion by selective water vapor absorption according to Fowle (*Astrophys. Jour.*, 42: 394, fig. 4). Curves (9) to (15), inclusive, show transmission after both scattering and absorption; they were computed by subtracting (16) from (2) to (8), and allowing for estimated selective absorption by the permanent gases. Air mass is designated by $m$; centimeters of precipitable water, by $w$.

spectral range and plotted with $m$ as abscissa and intensity of radiation as ordinate, since the intensity distribution outside the atmosphere is known. From the family of curves for the spectral range of $I$, the value of $\beta$ for any observed value of $I$ may be read off. A similar family of curves for $I_m$ may be constructed, from which the value of $I_m$ for any $\beta$ may be read off; the difference between this value and the observed value of $I_m$ is the depletion by selective atmospheric absorption. The absorption by the permanent gases can be estimated (*Smiths. Misc. Coll.*, Vol. 81, No. 11); and from the remainder, the depth of water $w$ that would be formed if all the water vapor above the point of observation were precipitated may be

[12] See W. J. Humphreys, *Physics of the Air*, 2 ed., pp. 537–546; L. V. King, On the scattering and absorption of light in gaseous media, with applications to the intensity of sky radiation, *Phil. Trans.*, A212: 375–434, 1913. F. E. Fowle, The atmospheric scattering of light, *Smith. Misc. Coll.*, Vol. 69, No. 3, 1918.

Haurwitz, Harvard Metl. Studies, No. 1; H. Wexler, Mo. Wea. Rev., 62: 397–402, 1934; H. H. Kimball, Mo. Wea. Rev., 62: 330–333, 1934.)

The measurements at Washington and Blue Hill of the solar radiation transmitted by the color screens, and the deduced values of $\beta$ and $w$, together with the air mass type at the time, are published monthly in the Review.

## *Daylight Illumination*

Figure 2 shows the spectral range of the solar radiant energy that reaches the surface of the earth, together with the extent of the range to which the human eye is sensitive and which is commonly termed *visible* radiation. The figure shows the way in which the position of the maximum intensity shifts from the ultraviolet to the infrared with increase in air mass; because of this shift, the ratio of total solar and sky radiation to the visible component of this total radiation undergoes large variations.

Measurements of daylight illumination on a horizontal surface freely exposed to both the sun and the total hemisphere of the sky, and also on a horizontal surface exposed to the sky alone, were first made by the Weather Bureau at Mount Weather, Va., in 1913.[41] Readings were taken only with either clear or uniformly clouded skies, because with partly cloudy skies the illumination varies so rapidly that observations are valueless.

A Sharp-Millar photometer with certain modifications [42] (fig. 22) has been adopted by the Weather Bureau for this work: A blue filter is placed in the optical train between the comparison lamp and the matching field, and an orange filter between the sky and the matching field, to obtain proper color relations; a compensating test-plate is used to eliminate errors at low sun. The whole apparatus has been calibrated frequently at the United States Bureau of Standards, to assure a thorough knowledge of the transmission factors, of the corrections to be applied to the electrical measuring devices, and of the candlepower of the comparison lamp with known current.

At Mount Weather, a maximum illumination of 10,000 foot-candles occurs with clear skies in midsummer at noon, as compared with 3,600 foot-candles at noon in January.[43]

The ratio of skylight illumination to total illumination on a horizontal surface at noon in midsummer varies from one-third to one-tenth, while in winter the variation is from one-half to one-fifth.

Table 8 gives the relation between total solar radiant energy and illumination in foot-candles at various solar altitudes for Mount Weather and Washington (*Cf.* Mo. WEA. REV., 52:473–479, 1925; and *Trans. Inter. Illum. Congress*, 1928).

From the Mount Weather illumination data, and pyrheliometric data obtained at Washington, Madison, Lincoln, and Sante Fe, Kimball [44] prepared charts showing the illumination in foot-candles by hours of the day and months of the year, on horizontal, vertical, and sloping surfaces at several different latitudes, produced by total solar and sky radiation, and also by direct solar radiation alone.

In 1921 a comprehensive program of sky brightness measurements was conducted by the Weather Bureau at Washington and Chicago.[45] At each of these stations, measurements were made with clear and with uniformly cloudy skies, at solar altitudes of 0°, 20°, 40°, 60°, and 70°. A complete series of readings included measurements of sky brightness at 2°, 15°, 30°, 45°, 60°, 75°, and 90° above the horizon on vertical circles at azimuths of 0°, 45°, 90°, 135°, and 180° from the solar vertical. Charts on the stereographic projection were prepared showing the distribution of sky brightness, and giving values in milli-lamberts for each 10° segment of the sky, for different solar altitudes and for clear, cloudy, and thinly clouded skies.

The results of this investigation may be briefly summarized as follows:

[41] Herbert H. Kimball. Photometric Measurements of Daylight Illumination on a Horizontal Surface at Mount Weather, Va. Mo. WEA. REV., 42: 650–653, 1914.

[42] Clayton H. Sharp, and Preston S. Millar, A New Universal Photometer, *Electrician*, 60: 562–565, 1908. *Jour. Opt. Soc. Amer.*, 10: 369–371.

[43] After correction for the difference in altitude between Mount Weather and Davos Platz, Switzerland, the maximum intensity is in good accord with values obtained by Switzer and Dorno. See C. Dorno, Physik der Sonnen und Himmelstrahlung, *Die Wissenschaft*, 63: 46.

[44] Herbert H. Kimball, Variations in the total and luminous solar radiation with geographical position in the United States, Mo. WEA. REV., 47: 785, 1919.

[45] Herbert H. Kimball and Irving F. Hand, Sky brightness and Daylight Illumination Measurements, Mo. WEA. REV., 49: 481–488, 1921; Daylight Illumination on Horizontal, Vertical, and Sloping Surfaces, Mo. WEA. REV., 50: 615–628, 1922 (*Cf. Trans. Illum. Eng. Soc.*, 16: 255–283; 18: 434–474; Mo. WEA. REV., 53: 448).

(1) A maximum illumination of 11,000 foot-candles occurs at Washington at noon in midsummer, as compared with about 10,000 on Mount Weather at the same period.

(2) With a cloudy sky, the illumination on a horizontal surface is nearly twice that on a vertical surface, because the region of maximum sky brightness is in or near the zenith.

(3) With high sun, as at midday in summer, the illumination from a cloudy sky averages higher than the illumination from a clear sky, except on vertical surfaces facing the sun.

(4) The maximum illumination from a clear sky occurs on vertical surfaces facing the sun, from early June to early September between 8:30 a. m. and 3:30 p. m., when it is about 1,400 foot-candles.

(5) The minimum illumination from skylight is on a vertical surface facing away from the sun.

(6) In the Loop District in Chicago the illumination from a cloudless sky averages about two-thirds the illumination at Washington on a similar surface with a clear sky. This, of course, is because of the smoke in Chicago.

(7) The total solar and sky illumination generally increases on surfaces sloping toward the south until the angle of slope reaches 20°, except with low sun during summer months.

(8) At Washington, the illumination from a clear sky on both horizontal and vertical surfaces varies between 150 and 60 percent of the average values; from a cloudy sky, between 200 and 30 percent. The illumination from a sky partly covered with white clouds is, on a horizontal surface, three to four times that from a clear sky; on a vertical surface, two to three times. With rain falling, the illumination is about half that from a cloudy sky.

Very recently, experiments have been conducted at Washington, D. C., with a Weston photronic cell, mounted horizontally under a hemispherical Uviol glass cover, to record daylight illumination. A report on the results of these experiments will be published in the REVIEW in the near future.

During severe thunderstorms, the illumination is sometimes reduced to less than 1 percent of that with a clear sky. Such a condition is of great importance to electric power companies, because when natural illumination falls sharply, the use of current for lighting purposes increases rapidly; and if the company is not prepared for the suddenly increased demand on its lines, serious damage to electrical equipment may result. It is a general practice, therefore, to maintain substations at points some miles in the directions from which thunderstorms usually approach, in order that additional generators may be started in sufficient time.

### *Ultraviolet Radiation*

The Weather Bureau has not as yet engaged to any great extent in the measurement of the ultra-violet component of solar radiation. From December 1926 to March 1927 the simple chemical method of Webster [46] was tried, in which the amount of bleaching of a methylene-blue-acetone-water solution, exposed to sunlight in quartz tubes, supposedly gives an approximate measure of ultra-violet intensity; but the trial of the method indicated that the results depend upon so many factors, such as the purity of the chemicals and their temperature (which latter is partly dependent upon wind), as to be only very rough.

[46] Herbert H. Kimball, and Irving F. Hand. *Bull. Nat. Res. Counc.*, No. 61, p. 123–125, Washington, 1927.

Measurements of ultra-violet solar radiation are now being initiated with an apparatus, designed by Coblentz and Stair [47] and consisting of titanium photoelectric cells with a balanced amplifier of the Wheatstone bridge type, recording on a microammeter; the measurements are in absolute units.

### SKY POLARIZATION AND BLUENESS

The Pickering polarimeter is used at both Washington and Madison for skylight polarization measurements. The instrument consists essentially of a grid, formed of lead bars spaced at intervals equal to their width. The grid is mounted on the end of a metal tube, and at a proper distance from it is placed a double-image prism that separates the images to exactly the width of the bars. When properly focused, and an interposed nicol turned so that the two images are equally bright, the field appears uniform; the slightest turn of the nicol restores the alternate light and dark bands. Observations consist of reading a graduated dial when the field becomes of uniform intensity; the cosine of the angle of rotation gives the percentage of polarization. The instrument is mounted on an upright post, and is equipped with adjustments in both altitude and declination; it is properly adjusted when a small spot of light falls on a cross on a metal disk. Observations are taken at air mass 2.0 on a point in the solar vertical 90° from the sun (ordinarily the point of maximum polarization).

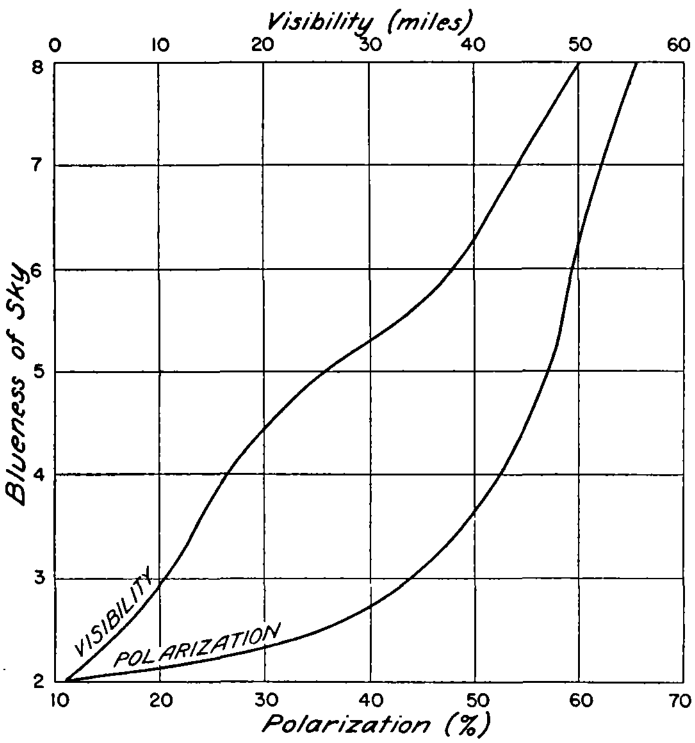



FIGURE 23.—Relations of visibility and sky polarization to sky blueness. See table 11.

A nicol prism is the best nucleus known for instruments intended to measure sky polarization. A recent attempt to fabricate a recording polarimeter by the use of a well-known organic substitute for nicols was abandoned when it was discovered that this material functioned properly only at visible wave-lengths.

Single nicols are useful in locating and studying clouds that otherwise are invisible.[48]

The polariscope is used to observe the location of the neutral points. This instrument consists essentially of a triangular sheet of heavy aluminum, with a swinging arm that may be clamped when a neutral point is found, to permit the determination of the angular height of the point; on one edge of the plate is an optical train, through which polarized skylight gives a field of vertical colored straight lines that disappear when the instrument is pointed toward a neutral point.

Tables 9 and 10 give the results of polarization measurements at Washington, D. C., and Madison, Wis. The original observations in detail are in the Weather Bureau files. Comparisons of polarization measurements with normal incidence intensities at air mass 2 (sun 30° above the horizon) show an increase in polarization with increase of normal intensity, provided the atmosphere is free from dust and cloud, and the ground has no snow or ice cover; reflection from these causes affects the polarization measurements to the point where they finally become valueless.

Many relations have been found between polarization of skylight and other meteorological quantities, especially visibility, relative humidity, vapor pressure,[49] and blueness of the sky.

Table 11 gives the means of all the polarization and sky blueness measurements at Washington, arranged in order of darkening shades of blue. Sky blueness observations consist simply of matching the color of the sky, at the point where polarization readings are made, against a standard series of blue cards of varying shades. Similar observations are made at the Blue Hill Observatory of Harvard University; both sets of color cards were furnished by F. Linke of the Universitäts-Instituts für Meteorologie und Geophysik, Frankfurt-am-Main, Germany. Sky blueness measurements have also been made by Thomson [50] at Apia, Samoa.

The visibility determinations were made in the usual way, by selecting from a large number of points at known distances the farthest one that could be seen with the unaided eye. It is well known that this type of observation is one of the most difficult to standardize. Figure 23 gives the same data as table 11, with blueness as ordinate, and polarization and visibility as abscissae. There is a very smooth relation between blueness and polarization; but, as might be expected, visibility distances do not plot so well.

### SURFACE REFLECTION AND EARTH RADIATION

Of the radiant energy incident on the earth's atmosphere, a portion is reflected and scattered directly back to interplanetary space during passage through the atmosphere; a small part of the remainder is absorbed in the atmosphere, while the rest reaches the surface of the earth either in the direct solar beam or as diffuse scattered light from the sky. Part of the radiation incident on the surface is reflected, and the remainder absorbed; a portion of the reflected radiation escapes directly to space. By the reflection of radiation in the atmosphere and at the surface, and by reradiation of energy absorbed in the atmosphere and on the surface, the earth is continually sending out radiant energy to space, and in the long run emits the same amount that is received from the

[47] W. W. Coblentz, Methods of Evaluating Ultraviolet Solar Radiation in Absolute Units, Mo. WEA. REV., 64: 319–321, 1936.

[48] Irving F. Hand. An aid in locating and studying clouds. Mo. WEA. REV., 61: 302–303, 1933.

[49] Irving F. Hand. Blue-Sky Measurements. Mo. WEA. REV., 55: 235–236, 1927.

[50] Andrew Thomson. Blue-Sky Measurements at Apia, Samoa. Mo. WEA. REV. 56: 499, 1928.

sun. (See C. G. Abbot, Radiation of the planet Earth to space, *Smith. Misc. Coll.*, Vol. 82, No. 3.) Measurements of surface reflection, and of radiation from the surface and from the atmosphere, are coordinate in importance with observations of incident solar radiation; the ceaseless flows and transformations of energy are fundamental in the dynamical mechanism of the atmospheric and oceanic circulations. (See, e. g., Mo. Wea. Rev., 59: 476–479, 1931; 57: 491–498, 1929.)

### *Reflectivity of Natural Surfaces*

In 1929 a Munro photometer, especially designed for measuring the reflection from ground and water surfaces from airplanes, was received from L. F. Richardson of London; and with it, the Weather Bureau took part in an international program of observations sponsored by the International Union of Geodesy and Geophysics.[51] The instrument has an optical train about 1 meter in length; on one end of the cylindrical metal casing is a brass head with two windows, one of fixed diameter facing the sky, and the other containing an iris diaphragm facing the ground. A soft-rubber eyepiece prevents possible injury when observing in a turbulent atmosphere.

Readings are made only under uniformly clouded skies, when the relation of the brightness of the zenithal point to that of the entire sky is well known.[45] The photometer was mounted on the side of an open cock-pit of an army observation plane, and flights were made over many kinds of surfaces including differently colored ploughed fields, forests of evergreen and of deciduous trees in varying states of foliage and color, level and hilly sections, freshly fallen and older snow surfaces, cities, rivers, and the ocean.

The observations[52] show a marked weakness of the green component in light reflected from a light-colored ploughed field. Most remarkable is the strength of the red component in light from grassy fields and forests; one reason why the green is so predominant to the eye, but becomes secondary in photometric measurements, is the fact that both the greatest sensitivity of the eye and the maximum point on the solar spectral energy curve lie in the green. It is also known that chlorophyll is fluorescent, reflecting back a considerable red component; while leaves, both during the growing season and immediately after the decomposition of the chlorophyll in the autumn, contain two coloring agents, xanthophyll and carotin, that introduce a strong red component.

The albedo of snow surfaces is too large to be measured with the above type of photometer. (See Mo. Wea. Rev., 58: 59–60, 1930, for observations with another instrument.) Among other surfaces observed, seashore sand and light-hued ploughed fields reflected the greatest percentages of total light; forested areas on steep slopes, the least. Clean rivers reflected the most green, and forest areas the least. Grassy fields, muddy rivers, and ordinary forest areas showed the largest amounts of red, while dark-hued ploughed fields and cities reflected the least. Readings with a blue filter were difficult to make because it took so long for the eye to become accustomed to this nearly monochromatic short-wave radiation; the few measurements obtained with this filter were highest over light colored ploughed fields, and least over dark-hued ploughed fields and forest areas (*Cf.* Ångström, *Geograf. Ann.*, 7:323, 1925).

[51] L. F. Richardson. Union Géodésique et géophysique Internationale, Section de Météorologie. Troisième Assemblée Générale: Prague, 1927. Cambridge, 1928.

[52] Herbert H. Kimball and Irving F. Hand. Reflectivity of Different Kinds of Surfaces. Mo. Wea. Rev., 58: 280–282, 1930.

Other instruments are also available for reflectivity measurements. (See e. g., Mo. Wea. Rev., 59:118, 1931.)

### *Terrestrial Radiation*

In 1918 four pyrgeometers were constructed for measuring net out-going radiation from a blackened surface; the thermoelectric junctions were made by W. W. Coblentz of the United States Bureau of Standards,[53] and the mountings were fabricated in the Weather Bureau machine shop.

The pyrgeometer, figure 25, is a modification of the Ångström electrical compensation pyrheliometer;[54] it has two blackened manganin strips and two gold-plated strips, and the procedure in using it is to determine the current necessary to maintain temperature equilibrium between the bright and the black strips when they are exposed to the night sky. Thermocouple junctions are attached to the under sides of the strips. The calibration was made by the Weather Bureau, by means of the Stefan-Boltzmann law

$$R=\sigma(T_1^4-T_2^4)$$

in the form

$$T=Ki^2=\sigma(T_1-T_2),$$

where $R$ is the rate at which heat is exchanged by radiation, $K$ is a constant depending upon the dimensions and electrical properties of the black and gold-plated strips, $i$ is the amperage of the heating current, $\sigma$ is the radiation constant for a black body (taken to be $8.18\times10^{-11}$ gram calories per minute per square centimeter, or 6½ percent higher than the value used by both K. and A. Ångström), $T_1$ the temperature of the pyrgeometer, and $T_2$ the temperature to which it is radiating.

The results[55] of nocturnal radiation measurements at Mount Weather, Va., Washington, D. C., Ellijay, N. C., and Highlands, N. C., are in close accord with those obtained by Ångström[56] after allowance for the difference in the values of $\sigma$ employed. They show that the temperature of the surface air is very closely related to the temperature of the ground, which in turn depends jointly upon the amount of energy absorbed from the radiation received from sun and sky by day and from the sky by night and the rate at which it is continually lost by radiation. At Washington during January the mean daily surface temperature changes but little from day to day, from which it may be inferred that the radiation absorbed must equal the losses from all sources. At this season of the year the net loss of energy by nocturnal radiation per square centimeter averages about 0.16 gram calories per minute. With increasing declination of the sun there is a progressive increase in the temperature of the ground surface, with resultant increase in net nocturnal radiation until an average maximum of about 0.2 gram calorie per minute is reached in July, with individual maximum values of about 0.3. At extremely low free-air temperatures, the rate of radiation from the earth decreases markedly; the net loss is also greatly decreased at night by clouds, or even changed to a net gain.[59]

[53] W. W. Coblentz. Instruments and Methods Used in Radiometry. Bull. U. S. Bur. Standards, 9: 7–63, 1913.

[54] Knut Ångström, Über die Andwendung der elektrischen Kompensations-methode zur Bestimming der nachlichten Ausstrahlung, *Nova Acta, Regiae societatis Upsaliensis*, Ser. IV, Vol. 1, No. 2, Upsala, 1908; Mo. Wea. Rev., 46: 57–61, 1918; *Smith. Misc. Coll.*, Vol. 65, No. 3.

[55] Herbert H. Kimball, Nocturnal Radiation Measurements, Mo. Wea. Rev., 46: 57–70, 1918. *Cf. Rept. Chief of Weather Bureau* 1913–14, p. 14.

[56] Anders Ångström. A study of the radiation of the atmosphere. *Smith. Misc. Coll.*' Vol. 65, No. 3, 1915.

[59] See J. C. Ballard. Some outgoing-radiation and surface-temperature measurements at Fargo, N. Dak. *Trans. Amer. Geophys. Union* 1937, Pt. I, pp. 127–130.

Earth radiation is a factor of fundamental importance in many dynamical phenomena of the atmosphere. In particular, it is the process by which great masses of cold air accumulate in the polar regions in winter until an outbreak to lower latitudes eventually occurs in the form of a "cold wave."[57] Terrestrial radiation measurements with an instrument called the melikeron[58] have recently been made by the Weather Bureau at a few northern stations in connection with an investigation of the formation and southward propagation of polar air masses.[59]

Nocturnal radiation measurements have also been made during investigations of protection from frost by heating. It was found[60] that a dense smoke-cloud diminishes nocturnal radiation on an average by about 0.11 gram calories per minute per square centimeter, with maximum effects of nearly 0.30 gram calories; but that the actual heating effect of the more efficient types of oil-burners plays a far more important part in protecting orchards from frost than does the smoke-cloud.[61]

### ATMOSPHERIC DUST AND ATMOSPHERIC POLLUTION

At a meeting in Rome, May 1922, 12 countries affiliated with the International Union of Geodesy and Geophysics agreed to participate in an international study of the dust content of the atmosphere; and a representative of each country was allotted an Owens dust counter as the principal instrument for the purpose.

This instrument (fig. 26) consists of three essential parts: (1) The so-called dampening chamber is a nickel-plated brass tube 2½ cm in diameter and 15 cm in length, open at one end and lined with chemically pure white blotting paper which is saturated with distilled water immediately before using. (2) The other end of this tube fits onto a head containing a narrow slot 1 cm long; and above this head is a bed for holding a microscope cover-glass, which latter should not exceed 0.15 mm in thickness. With the cover glass inserted, a cap containing a three-prong spring is screwed down, holding the glass firmly in place. (3) A passageway leads from the space between the slot and the cover glass to a one-way suction pump, by means of which the pressure above the slot may be suddenly reduced and thus cause the saturated air to pass at high velocity through the slot from the dampening chamber and impinge perpendicularly on the cover glass. The sudden reduction in pressure cools the already saturated air below its dew-point, and moisture is condensed on the dust particles. The high speed of the particles causes them to adhere to the cover glass and if the glass is removed immediately, the line of moisture containing the particles will be visible.

After the moisture has evaporated, the cover-glass is mounted and hermetically sealed on a microscope slide, dust side down.

The dust line is located by dark-field illumination under the microscope, after which the particles are counted under 1,000-diameter magnification through a fluorite oil-immersion objective. Slightly higher magnification is used to identify individual particles. The length of the dust line in units of the net-ruled ocular is noted; the particles within a rectangle bounded by the width of the line and the sides of a single square of the rulings are counted, and this number is multiplied by a factor that depends upon the number of strokes taken with the pump when securing the sample. Both the number of particles per cubic centimeter in the atmosphere, and their average diameter are estimated; the mass varies as the cube of the diameter.

Irrespective of the magnification used, the smallest particle that may be seen is about $0.2\mu$ in diameter; the largest is limited chiefly by the width of the slot, but rarely exceeds $10\mu$.

The Weather Bureau began observations in the latter part of 1922. Measurements were made at Washington, D. C., on each working day at 8 a. m.; and many observations were also taken in other cities, on mountain tops, and during unusual atmospheric conditions at Washington.[62] A number of airplane flights were made to determine the vertical and seasonal distribution of atmospheric dust. The complete original data are in the Weather Bureau files.

Table 12 gives the monthly means, and maximum and minimum values, obtained on the campus of the American University, District of Columbia, from 1922 to 1931. The mean for the entire series is 772 particles per cubic centimeter; the average size of the particles is close to $1.0\mu$, which agrees well with Ångström's observations.[63]

Ångström has derived formulae to determine approximately the amount of scattering and absorption of solar radiation by dry dust. However, these formulae assume definite average particle sizes. Angström states that in general the diameters of atmospheric dust particles vary from $1.0\mu$ to $1.5\mu$; but after violent volcanic eruptions the value may decrease to as low as $0.5\mu$.[64]

From all the observations at Washington, the following relation between visibility and number of dust particles at that station was derived:

$$C=NhD, \tag{4}$$

where $N$ is the number of dust particles per cubic centimeter, $h$ the relative humidity, and $D$ the visibility in miles. If we omit days with a visibility of 10 miles or less, the value of $C$ is 435,000; with all observations, $C$=390,000. The wind plays a most important part at this station in determining the number of particles; an easterly component brings city smoke and dust, and the count increases rapidly, while a strong northwest wind brings minimum counts.

Except in dust storms, atmospheric contamination generally is a maximum in cities, and is an important source of depletion of the antirachitic ultraviolet radiation; both dust storms and city atmospheric pollution decrease the ultraviolet in far greater proportion than they do the total solar and sky radiation. During a dust storm on March 18, 1937, at Lincoln, Nebr., with a sky free from clouds, incident radiation was only 0.06 gram calorie per minute per square centimeter at 9 a. m., or about 7 percent of the normal for that time of day and year. In fact, the in-

[57] H. Wexler, Cooling in the Lower Atmosphere and the structure of polar continental air, Mo. Wea. Rev., 64: 122-136, 1936; Formation of Polar Anticyclones, Mo. Wea. Rev., 65: 229–236, 1937.

[58] L. B. Aldrich. The Melikeron. *Smith. Misc. Coll.*, Vol. 72, No. 13, 1922.

[59] See J. C. Ballard. Some outgoing-radiation and surface-temperature measurements at Fargo, N. Dak. *Trans. Amer. Geophys. Union* 1937, Pt. I, pp. 127–130.

[60] Herbert H. Kimball and Floyd D. Young. Smudging as a protection from frost. Mo. Wea. Rev., 48: 461–462, 1920.

[61] See also Herbert H. Kimball and B. G. MacIntire. Efficiency of Smoke Screens as a protection from frost, Mo. Wea. Rev., 51: 396–399, 1923, where it is shown by further experimental investigations that frost protection by chemical smokes, such as used for smoke-screens during the World War, is impracticable.

[62] Herbert H. Kimball and Irving F. Hand, Investigations of the Dust Content of the Atmosphere, Mo. Wea. Rev., 52: 133–139, 1924; 53: 243-246, 1925; 59: 349–352, 1931. Irving F. Hand, The Character and Magnitude of the Dense Dust Cloud that passed over Washington, D. C., May 11, 1934, Mo. Wea. Rev., 62: 156–157, 1934; *cf.* Mo. Wea. Rev., 54: 19–20, 1926; 62:15, 1926. Irving F. Hand, Mountain and Valley Atmospheric Dust Measurements, Mo. Wea. Rev., 61: 169, 1933. Irving F. Hand, Effect of Local Smoke on Visibility and Solar Radiation, Mo. Wea. Rev., 53: 147–148, 1935; *cf.* 57:18, 1929.

[63] Anders Ångström. On Atmospheric Transmission of Sun Radiation II. *Geografiska Annaler*, 1930, H. 2, p. 3, 1930.

[64] It has long been known that violent volcanic eruptions which project large quantities of volcanic dust to great heights appreciably decrease the amount of solar radiation received at the surface of the earth, and at times perceptibly influence the temperature. See: W. J. Humphreys, *Physics of the Air*, 2 ed., New York, 1929; The Greenhouse Effect of Volcanic Dust, Mo. Wea. Rev., 65: 261–262, 1937. H. H. Kimball, *Bull. Mt. Weath. Obs.*, 3: 111; 5: 301; 6: 205–220, 1914. H. H. Kimball, Mo. Wea. Rev., 41: 153–159, 1913; 46: 355–356, 1918; 52: 527–529, 1924. W. B. Rimmer, *Gerl. Beit. z. Geophys.*, 50: 388–393, 1937.

coming radiation at that time was far less than the normal outgoing radiation for that season.

Many different kinds of dust particles were observed during the investigations. Spores, diatoms, crystals of calcite and gypsum, organic matter of many kinds, volcanic glass, spicules, and mineral particles of many varieties were found. A search was made for cosmic dust; but the difficulty of identifying it and distinguishing it with certainty from products of combustion prevented any positive identifications.

On one occasion, a diatom of unusual appearance was identified by Albert Mann of the Smithsonian Institution as the *Navicula Borealis*, indigenous to Alaska only; the weather maps for the period immediately preceding the collection of this diatom showed that strong northwest winds had prevailed. On another occasion a microscopist of the Bureau of Plant Industry identified a spore obtained in February, long before spores were set free in the latitude of Washington, as being indigenous to Florida only; again the weather maps indicated that strong southerly winds had prevailed for some days. Rust spores obtained at an elevation of 16,000 feet were found to be potent, as they responded to agar cultures.

The season and the conditions of cloudiness have marked effects on the vertical distribution of atmospheric dust. With clear skies, a larger number of dust particles often were found at elevations of one or two thousand feet than near the ground; with cloudy skies, the number of particles diminished rather regularly with height to extremely small values at the top of the dust layer.

During 1926 and 1927, the Weather Bureau also made determinations of the amount of sulphur in the atmosphere.[65] Excessive quantities of sulphur are detrimental to both health and property. In one extreme case, the combination of a large sulphur content with the water vapor which is always present formed sulphuric acid to such an extent that the outer surface of a white marble building was changed into gypsum to a depth of 6 millimeters. Evidences of the ravages of sulphur may be seen in the vicinity of many railroad yards and manufacturing plants; mortar between bricks becomes loosened, metals are corroded and buildings in general take on an exceedingly dingy appearance. Ordinarily two parts of sulphur in a million by volume give a noticeably sulphurous odor to the atmosphere.

[65] Herbert H. Kimball and Irving F. Hand. Measurements of the Sulphur Content of the Atmosphere. Mo. Wea. Rev., 59: 351-352, 1931.

Sulphur determinations were made by placing equal quantities of a solution of distilled water, iodine, potassium iodide, and soluble starch in two 20-liter bottles, each bottle being tightly sealed but provided with a ground-glass stopcock inserted through a sulphur-free rubber stopper. The pressure within one bottle was reduced to one-half normal. Both bottles were shaken vigorously; the stopcock of the partially evacuated bottle was then opened, the bottle again shaken until normal pressure was restored within, and the liquid then titrated until a color match with the other bottle had been obtained.

All determinations were made on the campus of the American University in the northwest part of Washington, D. C., where the sulphur content of the atmosphere varied considerably, depending upon the wind direction. An easterly wind brought contamination from the city, while a westerly wind usually brought country air. Some contamination resulted from a blast furnace on an adjoining portion of the campus.

An amount of sulphur in excess of one part in a million by volume was observed on only 15 days out of the 600 on which measurements were made. Five of these days were in October, 1928, when the blast furnace was in almost continual operation. In general, a large number of dust particles were observed on days with the larger amounts of sulphur. The average for the entire observing period was close to one part of sulphur in 10 million by volume.

## ACKNOWLEDGMENT

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TABLE 1.—*Pyrheliometric stations*

| Location | Direction of | N. lat. | W. long. | Instruments | Pyrheliom. Altitude, m.s.l. | Established |
|---|---|---|---|---|---|---|
| | | ° ′ | ° ′ | | *Feet* | |
| Washington, D. C. (American university). | U. S. Weather Bureau | 38 56 | 77 05 | Smithsonian, Marvin, Angström comp., Weath. Bur. pyrhel., Eppley-Coblentz pyrhel. | 397 | October 1914. |
| | | | | Eppley; Engelhard, and L. & N. rec | 414 | |
| | | | | Moll thermopile | | |
| | | | | Ultraviolet and visible radiation | | |
| | | | | Polarimeter, Linke color cards, Owens dust counter, photometer, Richardson airplane photometer, pyrgeometer. | | |
| Madison, Wis. (University of Wisconsin). | do | 43 05 | 89 23 | Marvin | 974 | July 1910.[1] |
| | | | | Eppley; L. & N. rec | 1,009 | |
| | | | | Polarimeter | | |
| Lincoln, Nebr. (University of Nebraska). | do | 40 50 | 96 41 | Marvin | 1,225 | November 1911.[2] |
| | | | | Eppley; L. & N. rec | 1,250 | |
| Chicago, Ill. (University of Chicago) | do | 41 47 | 87 25 | Eppley; Engelhard rec | 688 | September 1923. |
| New York, N. Y. (Central Park Meteorological Observatory). | do | 40 46 | 73 58 | Eppley; Engelhard rec | 180 | April 1924. |
| | | | | Black bulb in vacuo | | |
| | | | | Owens automatic filter | | |
| Fresno, Calif | do | 36 43 | 119 49 | Eppley, Engelhard rec | 330 | January 1929. |
| Pittsburgh, Pa.[3] | do | 40 22 | 79 56 | do | 1,293 | January 1930.[3] |
| Fairbanks, Alaska | do | 64 52 | 147 39 | do | 500 | August 1931. |
| San Juan, P. R | do | 18 28 | 66 06 | do | 85 | May 1935. |
| Gainesville, Fla.[4] | University of Florida | 29 39 | 82 21 | Moll; Richárd rec. microammeter | 233 | January 1930.[4] |
| Twin Falls, Idaho | U. S. Bureau Entomology and Plant Quarantine. | 42 29 | 114 25 | Eppley; Engelhard rec | 4,300 | January 1927. |
| La Jolla, Calif | Scripps Institute of Oceanography | 32 50 | 117 15 | do | 85 | January 1930.[5] |
| Miami, Fla. (Belle Isle Observatory, Coral Gables). | O. J. Sieplein | 25 41 | 80 12 | Callendar | 50 | July 1930. |

[1] Record of total solar and sky radiation started April 1911.
[2] Record of total solar and sky radiation started June 1915.
[3] See text. Discontinued in August 1936.
[4] Discontinued December 1933.
[5] See text; record not homogeneous.

TABLE 1.—*Pyrheliometric stations*—Continued

| Location | Direction of | N. lat. | W. long. | Instruments | Pyrheliom. Altitude, m.s.l. | Established |
|---|---|---|---|---|---|---|
| | | ° ′ | ° ′ | | *Feet* | |
| New Orleans, La. | Tulane University | 29 56 | 90 07 | Eppley; Richard rec. microammeter | 100 | March 1931. |
| Ithaca, N. Y. (Cornell University) | Department Pomology, N. Y. State College Agriculture. | 42 27 | 76 29 | Eppley; L. & N. rec. | 953 | January 1935. |
| Friday Harbor, Wash. | Oceanographic Laboratory, University of Washington. | 48 32 | 123 01 | Eppley; Engelhard rec. | 15 | July 1932. |
| Blue Hill, Mass. | Harvard University | 42 13 | 71 07 | Smithsonian; Eppley-Coblentz<br>Eppley; Engelhard and L. & N. rec.<br>Linke color cards | <br>640 | <br>September 1933. |
| Mount Washington, N. H.[6] | do | 44 16 | 71 18 | Eppley; Engelhard rec. | 6,270 | December 1933.[6] |
| Riverside, Calif. | University of California, College of Agriculture. | 33 58 | 117 28 | do | 1,051 | June 1933. |
| Newport, R. I. | Eppley Laboratory | 41 30 | 71 19 | Smithsonian, Eppley-Coblentz<br>Eppley; Engelhard and L. & N. rec. | <br>52 | <br>June 1937. |

[6] Discontinued March 1935. Record intermittent; see text.

TABLE 2.—*Weekly means of daily totals of solar and sky radiation on a horizontal surface, gram calories per square centimeter; stations are in order of increasing latitude*

| Station | San Juan | Miami | Gainesville | New Orleans | La Jolla | Riverside | Fresno | Washington | Pittsburgh | New York | Lincoln | Chicago | Blue Hill | Ithaca | Twin Falls | Madison | Mount Washington | Friday Harbor | Fairbanks | Mean, omitting San Juan, Mount Washington, and Fairbanks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number years data | 1 | 6 | 3 | 5 | 6 | 3 | 8 | 22 | 2 | 12 | 20 | 13 | 3 | 3 | 10 | 26 | 1 | 3 | 5 | |
| *Midweek date* | | | | | | | | | | | | | | | | | | | | |
| Jan. 4 | ------ | 295 | 222 | 146 | 245 | 234 | 148 | 153 | 89 | 103 | 175 | 81 | 143 | 100 | 165 | 129 | 94 | 68 | 8 | 156 |
| Jan. 11 | ------ | 300 | 209 | 193 | 254 | 245 | 163 | 152 | 97 | 108 | 185 | 92 | 154 | 96 | 169 | 134 | 115 | 76 | 10 | 164 |
| Jan. 18 | ------ | 275 | 214 | 202 | 239 | 273 | 189 | 163 | 107 | 113 | 196 | 99 | 182 | 121 | 184 | 156 | 132 | 90 | 15 | 175 |
| Jan. 25 | ------ | 332 | 237 | 206 | 260 | 280 | 208 | 180 | 110 | 154 | 226 | 120 | 207 | 165 | 189 | 185 | 134 | 98 | 26 | 197 |
| Feb. 1 | ------ | 351 | 249 | 233 | 253 | 267 | 216 | 204 | 121 | 149 | 224 | 119 | 238 | 208 | 203 | 188 | 172 | 100 | 36 | 208 |
| Feb. 8 | ------ | 351 | 273 | 262 | 265 | 279 | 248 | 213 | 148 | 161 | 262 | 136 | 250 | 206 | 216 | 207 | 226 | 112 | 49 | 224 |
| Feb. 15 | ------ | 349 | 310 | 284 | 274 | 297 | 294 | 222 | 170 | 168 | 272 | 141 | 261 | 195 | 260 | 225 | 225 | 119 | 70 | 240 |
| Feb. 22 | ------ | 374 | 343 | 292 | 314 | 296 | 340 | 261 | 175 | 200 | 298 | 183 | 291 | 208 | 273 | 254 | 226 | 136 | 104 | 279 |
| Mar. 1 | ------ | 364 | 382 | 286 | 336 | 378 | 382 | 289 | 176 | 242 | 342 | 209 | 306 | 224 | 300 | 280 | 258 | 153 | 144 | 291 |
| Mar. 8 | ------ | 376 | 402 | 294 | 333 | 413 | 403 | 309 | 200 | 263 | 358 | 210 | 314 | 222 | 338 | 299 | 250 | 201 | 153 | 308 |
| Mar. 15 | ------ | 421 | 394 | 324 | 348 | 425 | 422 | 326 | 219 | 271 | 377 | 216 | 334 | 248 | 349 | 313 | 231 | 251 | 193 | 327 |
| Mar. 22 | ------ | 477 | 418 | 346 | 375 | 427 | 455 | 333 | 222 | 286 | 395 | 241 | 350 | 298 | 390 | 318 | 286 | 314 | 172 | 353 |
| Mar. 29 | ------ | 466 | 487 | 346 | 414 | 441 | 484 | 346 | 241 | 267 | 407 | 240 | 373 | 310 | 378 | 350 | 399 | 388 | 279 | 372 |
| Apr. 5 | ------ | 471 | 485 | 354 | 423 | 475 | 511 | 371 | 287 | 329 | 413 | 298 | 377 | 265 | 434 | 372 | 465 | 410 | 334 | 392 |
| Apr. 12 | ------ | 482 | 476 | 364 | 440 | 496 | 577 | 393 | 320 | 316 | 435 | 336 | 370 | 259 | 480 | 400 | 480 | 410 | 380 | 410 |
| Apr. 19 | 655 | 470 | 523 | 389 | 446 | 501 | 589 | 425 | 344 | 364 | 447 | 334 | 363 | 328 | 464 | 399 | 444 | 445 | 398 | 427 |
| Apr. 26 | 583 | 478 | 580 | 386 | 453 | 514 | 573 | 450 | 363 | 411 | 450 | 357 | 436 | 373 | 511 | 439 | 436 | 484 | 392 | 454 |
| May 3 | 485 | 525 | 584 | 381 | 462 | 560 | 626 | 456 | 377 | 389 | 475 | 371 | 486 | 398 | 513 | 438 | 480 | 559 | 401 | 475 |
| May 10 | 389 | 534 | 598 | 378 | 472 | 552 | 642 | 447 | 380 | 389 | 444 | 383 | 497 | 451 | 500 | 444 | 545 | 572 | 417 | 485 |
| May 17 | 483 | 490 | 605 | 375 | 438 | 560 | 667 | 471 | 416 | 420 | 523 | 433 | 548 | 579 | 623 | 482 | 563 | 546 | 444 | 511 |
| May 24 | 533 | 497 | 590 | 408 | 498 | 568 | 676 | 507 | 462 | 446 | 557 | 458 | 574 | 582 | 644 | 492 | 569 | 523 | 442 | 530 |
| May 31 | 544 | 472 | 543 | 455 | 472 | 560 | 676 | 524 | 478 | 461 | 520 | 461 | 520 | 506 | 580 | 497 | 620 | 529 | 432 | 516 |
| June 7 | 576 | 526 | 508 | 458 | 434 | 575 | 648 | 495 | 477 | 428 | 550 | 444 | 506 | 490 | 566 | 510 | 582 | 572 | 469 | 512 |
| June 14 | 627 | 481 | 464 | 439 | 434 | 601 | 701 | 499 | 484 | 435 | 546 | 451 | 512 | 514 | 637 | 507 | 462 | 601 | 502 | 519 |
| June 21 | 643 | 459 | 440 | 420 | 485 | 614 | 721 | 494 | 490 | 434 | 576 | 464 | 546 | 505 | 698 | 523 | 466 | 600 | 499 | 529 |
| June 28 | 627 | 515 | 468 | 406 | 503 | 613 | 728 | 531 | 478 | 450 | 603 | 437 | 580 | 520 | 656 | 532 | 448 | 576 | 474 | 537 |
| July 5 | 638 | 515 | 492 | 400 | 432 | 614 | 704 | 513 | 476 | 454 | 589 | 465 | 555 | 552 | 603 | 529 | 487 | 576 | 446 | 529 |
| July 12 | 662 | 522 | 459 | 400 | 432 | 603 | 698 | 496 | 488 | 454 | 586 | 459 | 526 | 546 | 601 | 535 | -------- | 610 | 482 | 526 |
| July 19 | 668 | 513 | 464 | 396 | 453 | 580 | 687 | 484 | 487 | 426 | 583 | 460 | 509 | 526 | 606 | 519 | -------- | 595 | 411 | 518 |
| July 26 | 668 | 531 | 468 | 381 | 439 | 572 | 664 | 488 | 482 | 425 | 555 | 463 | 505 | 466 | 571 | 509 | -------- | 556 | 434 | 505 |
| Aug. 2 | 668 | 496 | 424 | 375 | 428 | 567 | 659 | 472 | 454 | 424 | 515 | 377 | 513 | 454 | 541 | 466 | -------- | 546 | 335 | 476 |
| Aug. 9 | 655 | 516 | 412 | 364 | 397 | 547 | 628 | 441 | 416 | 375 | 496 | 390 | 512 | 443 | 546 | 456 | -------- | 538 | 317 | 467 |
| Aug. 16 | 623 | 465 | 409 | 345 | 402 | 530 | 619 | 436 | 395 | 363 | 490 | 388 | 509 | 458 | 485 | 441 | -------- | 535 | 298 | 451 |
| Aug. 23 | 600 | 492 | 386 | 348 | 413 | 514 | 587 | 417 | 379 | 328 | 484 | 399 | 494 | 445 | 528 | 441 | 465 | 502 | 281 | 447 |
| Aug. 30 | 596 | 474 | 360 | 377 | 392 | 502 | 568 | 418 | 374 | 351 | 443 | 351 | 398 | 371 | 491 | 403 | 424 | 458 | 247 | 421 |
| Sept. 6 | 588 | 437 | 343 | 383 | 361 | 494 | 570 | 383 | 358 | 314 | 459 | 338 | 360 | 348 | 475 | 374 | 374 | 411 | 187 | 400 |
| Sept. 13 | 575 | 424 | 344 | 346 | 329 | 462 | 545 | 366 | 332 | 313 | 427 | 294 | 343 | 352 | 454 | 335 | 352 | 360 | 215 | 377 |
| Sept. 20 | 539 | 433 | 378 | 323 | 328 | 435 | 494 | 366 | 315 | 299 | 421 | 313 | 332 | 342 | 412 | 344 | 315 | 349 | 147 | 367 |
| Sept. 27 | 542 | 407 | 379 | 339 | 331 | 413 | 465 | 352 | 290 | 278 | 374 | 265 | 333 | 292 | 431 | 292 | 295 | 344 | 123 | 349 |
| Oct. 4 | 536 | 406 | 357 | 350 | 317 | 387 | 434 | 336 | 257 | 283 | 337 | 262 | 334 | 275 | 385 | 276 | 282 | 226 | 109 | 326 |
| Oct. 11 | 522 | 368 | 363 | 340 | 285 | 363 | 405 | 307 | 228 | 266 | 306 | 228 | 321 | 289 | 363 | 242 | 253 | 236 | 72 | 307 |
| Sept. 18 | 501 | 355 | 369 | 318 | 290 | 350 | 371 | 283 | 203 | 214 | 300 | 211 | 296 | 270 | 344 | 217 | 232 | 195 | 63 | 287 |
| Oct. 25 | 488 | 368 | 339 | 290 | 287 | 342 | 368 | 267 | 180 | 194 | 278 | 179 | 264 | 205 | 297 | 205 | 181 | 164 | 53 | 264 |
| Nov. 1 | 488 | 345 | 238 | 275 | 269 | 306 | 316 | 246 | 154 | 174 | 238 | 146 | 230 | 146 | 225 | 183 | 119 | 138 | 38 | 227 |
| Nov. 8 | 500 | 337 | 251 | 262 | 209 | 327 | 307 | 225 | 128 | 148 | 243 | 126 | 196 | 126 | 212 | 164 | 118 | 114 | 30 | 207 |
| Nov. 15 | 508 | 342 | 220 | 244 | 265 | 301 | 245 | 196 | 121 | 127 | 207 | 102 | 179 | 110 | 166 | 143 | 135 | 103 | 27 | 192 |
| Nov. 22 | 498 | 328 | 211 | 224 | 263 | 272 | 242 | 189 | 121 | 126 | 206 | 117 | 162 | 102 | 156 | 129 | 116 | 93 | 18 | 184 |
| Nov. 29 | 477 | 285 | 213 | 209 | 259 | 262 | 221 | 164 | 106 | 109 | 185 | 86 | 149 | 91 | 156 | 124 | 94 | 83 | 14 | 169 |
| Dec. 6 | 477 | 304 | 215 | 172 | 254 | 213 | 191 | 159 | 87 | 102 | 172 | 69 | 130 | 81 | 111 | 116 | 106 | 80 | 7 | 154 |
| Dec. 13 | 476 | 308 | 204 | 184 | 252 | 212 | 179 | 136 | 71 | 101 | 166 | 79 | 128 | 82 | 119 | 113 | 118 | 75 | 5 | 146 |
| Dec. 20 | 433 | 280 | 188 | 190 | 249 | 223 | 149 | 145 | 71 | 97 | 178 | 88 | 142 | 91 | 117 | 120 | 99 | 71 | 6 | 150 |
| Dec. 27 [1] | 368 | 283 | 249 | 168 | 236 | 220 | 138 | 149 | 84 | 115 | 174 | 85 | 148 | 100 | 133 | 123 | 86 | 68 | 5 | 155 |
| Means | ------ | 416 | 379 | 319 | 356 | 424 | 391 | 339 | 278 | 281 | 378 | 270 | 351 | 306 | 391 | 324 | -------- | 325 | 216 | 350 |

[1] 8-day period.

TABLE 3.—*Mean hourly totals of solar and sky radiation on a horizontal surface, Washington, D. C., 1927–36, inclusive (apparent solar time)*

| Gram-calories per square centimeter for hour ending | A. M. | | | | | | | | P. M. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8 | 9 | 10 | 11 | Noon | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| *Date* | | | | | | | | | | | | | | | | |
| Jan. 1 | ------- | ------- | ------- | 1.5 | 7.7 | 17.7 | 22.0 | 26.3 | 25.9 | 23.2 | 17.1 | 8.7 | 1.8 | ------- | ------- | ------- |
| Jan. 8 | ------- | ------- | ------- | 1.6 | 7.7 | 15.5 | 21.4 | 24.8 | 24.7 | 21.9 | 16.6 | 8.8 | 1.7 | ------- | ------- | ------- |
| Jan. 15 | ------- | ------- | ------- | 2.0 | 8.5 | 16.6 | 22.3 | 26.2 | 26.8 | 23.5 | 17.7 | 9.3 | 3.1 | ------- | ------- | ------- |
| Jan. 22 | ------- | ------- | ------- | 2.6 | 9.5 | 18.1 | 24.9 | 27.8 | 30.0 | 27.0 | 20.4 | 11.9 | 3.2 | ------- | ------- | ------- |
| Jan. 29 | ------- | ------- | ------- | 3.5 | 12.4 | 26.2 | 31.0 | 35.8 | 35.2 | 28.8 | 24.8 | 14.7 | 4.3 | ------- | ------- | ------- |
| Feb. 5 | ------- | ------- | 0.3 | 4.2 | 13.2 | 23.1 | 30.0 | 34.9 | 35.3 | 31.4 | 25.0 | 14.9 | 4.8 | 0.4 | ------- | ------- |
| Feb. 12 | ------- | ------- | .5 | 4.6 | 13.6 | 23.4 | 29.7 | 33.0 | 32.7 | 30.8 | 24.0 | 15.2 | 6.3 | .6 | ------- | ------- |
| Feb. 19 | ------- | ------- | .8 | 7.5 | 19.1 | 30.2 | 37.3 | 41.8 | 42.0 | 35.6 | 28.0 | 18.3 | 8.0 | .8 | ------- | ------- |
| Feb. 26 | ------- | ------- | 1.3 | 9.3 | 20.5 | 31.4 | 38.7 | 41.7 | 41.0 | 38.2 | 29.8 | 20.5 | 9.8 | 1.2 | ------- | ------- |
| Mar. 5 | ------- | ------- | 2.0 | 11.7 | 22.6 | 33.2 | 40.3 | 45.2 | 45.7 | 40.1 | 31.8 | 22.8 | 11.8 | 2.1 | ------- | ------- |
| Mar. 12 | ------- | ------- | 2.5 | 12.0 | 23.6 | 34.4 | 42.2 | 43.7 | 42.2 | 38.2 | 33.4 | 23.8 | 13.0 | 3.0 | ------- | ------- |
| Mar. 19 | ------- | 0.1 | 2.9 | 12.4 | 21.2 | 30.1 | 38.0 | 39.9 | 40.5 | 37.4 | 30.2 | 21.7 | 12.6 | 3.8 | 0.1 | ------- |
| Mar. 26 | ------- | .2 | 4.2 | 14.8 | 25.2 | 34.0 | 39.4 | 43.9 | 42.2 | 41.4 | 34.1 | 25.1 | 15.7 | 5.9 | .3 | ------- |
| Apr. 2 | ------- | .4 | 5.6 | 16.2 | 25.5 | 35.3 | 41.3 | 44.5 | 46.2 | 43.1 | 35.6 | 27.6 | 16.7 | 6.2 | .5 | ------- |
| Apr. 9 | ------- | .8 | 7.3 | 18.1 | 29.2 | 38.5 | 46.2 | 50.1 | 50.2 | 45.1 | 37.4 | 27.1 | 16.1 | 6.6 | .7 | ------- |
| Apr. 16 | ------- | 1.3 | 9.2 | 20.4 | 32.3 | 44.0 | 52.9 | 52.8 | 53.1 | 48.1 | 42.5 | 31.0 | 21.1 | 9.3 | 1.4 | ------- |
| Apr. 23 | ------- | 1.8 | 11.1 | 24.6 | 37.8 | 46.9 | 54.8 | 60.2 | 58.8 | 52.8 | 46.8 | 38.3 | 26.0 | 12.2 | 2.3 | ------- |
| Apr. 30 | ------- | 2.7 | 11.2 | 23.0 | 35.1 | 46.4 | 54.6 | 57.3 | 57.5 | 54.0 | 46.2 | 34.5 | 23.7 | 12.4 | 2.9 | ------- |
| May 7 | ------- | 2.8 | 10.4 | 21.7 | 31.6 | 40.0 | 48.1 | 53.7 | 54.0 | 51.4 | 44.2 | 33.1 | 23.7 | 12.1 | 2.8 | ------- |
| May 14 | 0.1 | 3.6 | 12.1 | 25.3 | 37.6 | 46.7 | 52.4 | 56.4 | 55.3 | 51.9 | 46.8 | 35.6 | 25.4 | 13.0 | 4.3 | 0.1 |
| May 21 | .2 | 4.4 | 14.8 | 27.8 | 40.5 | 53.6 | 59.9 | 63.0 | 64.3 | 60.5 | 51.2 | 40.6 | 27.6 | 14.9 | 4.3 | .2 |
| May 28 | .3 | 5.6 | 16.9 | 32.0 | 45.1 | 54.8 | 63.8 | 65.4 | 64.4 | 58.1 | 51.0 | 40.8 | 28.9 | 16.8 | 5.7 | .4 |
| June 4 | .5 | 5.6 | 15.8 | 30.2 | 40.2 | 50.3 | 56.0 | 59.5 | 58.5 | 55.7 | 47.6 | 38.6 | 25.7 | 14.4 | 5.5 | .5 |
| June 11 | .5 | 4.9 | 14.1 | 27.0 | 39.1 | 51.1 | 58.2 | 58.7 | 60.6 | 60.9 | 50.9 | 39.6 | 27.3 | 15.6 | 5.8 | .5 |
| June 18 | .6 | 6.0 | 16.2 | 28.7 | 40.4 | 50.5 | 56.5 | 59.1 | 59.0 | 54.2 | 46.8 | 37.5 | 27.9 | 16.7 | 5.8 | .6 |
| June 25 | .6 | 6.5 | 17.3 | 31.7 | 44.1 | 54.8 | 62.5 | 67.3 | 67.6 | 61.2 | 54.4 | 42.6 | 29.7 | 16.3 | 5.9 | .6 |
| July 2 | .5 | 5.8 | 17.2 | 30.8 | 43.3 | 54.0 | 62.0 | 67.4 | 66.0 | 63.0 | 55.5 | 41.7 | 30.0 | 17.5 | 6.5 | .5 |
| July 9 | .4 | 5.4 | 14.4 | 25.3 | 37.9 | 49.0 | 57.0 | 62.3 | 61.8 | 58.3 | 49.5 | 40.6 | 28.6 | 16.2 | 5.6 | .5 |
| July 16 | .3 | 5.4 | 14.8 | 26.7 | 37.7 | 49.3 | 55.7 | 61.0 | 60.2 | 55.3 | 48.5 | 38.3 | 25.9 | 14.4 | 5.0 | .3 |
| July 23 | .2 | 3.8 | 15.2 | 27.2 | 39.5 | 51.3 | 56.4 | 61.1 | 62.9 | 58.7 | 50.6 | 40.1 | 31.9 | 14.8 | 4.1 | .2 |
| July 30 | .1 | 3.2 | 12.1 | 25.4 | 38.3 | 48.6 | 57.2 | 61.5 | 63.5 | 58.1 | 51.1 | 38.4 | 26.6 | 14.2 | 3.6 | .1 |
| Aug. 6 | ------- | 2.4 | 11.1 | 22.5 | 34.8 | 43.9 | 51.6 | 53.2 | 55.3 | 52.1 | 46.3 | 35.0 | 22.7 | 11.3 | 2.6 | ------- |
| Aug. 13 | ------- | 2.0 | 9.5 | 22.0 | 33.2 | 44.7 | 52.5 | 54.8 | 56.2 | 54.8 | 45.9 | 35.1 | 23.2 | 10.8 | 2.1 | ------- |
| Aug. 20 | ------- | 1.5 | 8.4 | 20.1 | 31.3 | 41.7 | 49.0 | 54.6 | 54.5 | 49.8 | 46.2 | 36.9 | 21.7 | 10.1 | 1.8 | ------- |
| Aug. 27 | ------- | 1.0 | 7.6 | 19.0 | 31.1 | 41.9 | 49.7 | 54.8 | 53.9 | 52.3 | 43.7 | 30.6 | 19.6 | 7.9 | .9 | ------- |
| Sept. 3 | ------- | .6 | 6.0 | 16.6 | 27.5 | 38.9 | 44.8 | 51.8 | 50.3 | 45.9 | 37.7 | 29.8 | 17.9 | 7.5 | .8 | ------- |
| Sept. 10 | ------- | .4 | 5.3 | 15.6 | 26.4 | 36.1 | 43.4 | 47.4 | 48.4 | 43.1 | 37.5 | 28.1 | 17.0 | 6.0 | .5 | ------- |
| Sept. 17 | ------- | .2 | 4.4 | 16.9 | 29.0 | 39.8 | 46.9 | 50.3 | 50.3 | 46.5 | 40.2 | 28.6 | 15.3 | 4.8 | .2 | ------- |
| Sept. 24 | ------- | ------- | 3.4 | 14.5 | 26.6 | 38.6 | 45.8 | 49.8 | 51.4 | 48.4 | 40.8 | 28.7 | 16.2 | 4.0 | ------- | ------- |
| Oct. 1 | ------- | ------- | 2.4 | 13.2 | 27.9 | 38.1 | 43.2 | 49.8 | 50.7 | 46.4 | 38.8 | 26.0 | 13.2 | 2.6 | ------- | ------- |
| Oct. 8 | ------- | ------- | 1.8 | 10.8 | 23.4 | 34.1 | 42.8 | 46.3 | 45.8 | 43.4 | 35.3 | 23.7 | 11.4 | 1.6 | ------- | ------- |
| Oct. 15 | ------- | ------- | 1.1 | 8.9 | 20.7 | 31.4 | 39.3 | 44.1 | 43.7 | 39.4 | 32.1 | 19.9 | 9.0 | 1.2 | ------- | ------- |
| Oct. 22 | ------- | ------- | .8 | 6.8 | 17.3 | 30.0 | 37.8 | 41.3 | 40.9 | 37.7 | 29.8 | 18.4 | 7.4 | .8 | ------- | ------- |
| Oct. 29 | ------- | ------- | .5 | 5.5 | 15.4 | 24.9 | 31.7 | 35.8 | 36.4 | 32.6 | 25.8 | 16.1 | 5.9 | .4 | ------- | ------- |
| Nov. 5 | ------- | ------- | .3 | 4.4 | 13.7 | 22.2 | 30.2 | 33.1 | 33.4 | 28.5 | 23.0 | 13.8 | 4.6 | .3 | ------- | ------- |
| Nov. 12 | ------- | ------- | .1 | 3.1 | 10.4 | 19.0 | 26.0 | 30.0 | 29.6 | 24.6 | 18.8 | 10.9 | 3.4 | .1 | ------- | ------- |
| Nov. 19 | ------- | ------- | ------- | 2.5 | 10.2 | 19.8 | 27.0 | 31.0 | 30.5 | 25.6 | 19.8 | 10.9 | 2.8 | ------- | ------- | ------- |
| Nov. 26 | ------- | ------- | ------- | 1.8 | 8.6 | 18.1 | 24.3 | 26.5 | 26.9 | 23.4 | 16.0 | 9.6 | 2.3 | ------- | ------- | ------- |
| Dec. 3 | ------- | ------- | ------- | 1.6 | 8.3 | 17.1 | 24.4 | 30.2 | 29.5 | 25.5 | 18.1 | 9.4 | 1.8 | ------- | ------- | ------- |
| Dec. 10 | ------- | ------- | ------- | 1.2 | 6.4 | 13.4 | 17.4 | 20.1 | 19.7 | 17.0 | 12.8 | 6.8 | 1.3 | ------- | ------- | ------- |
| Dec. 17 | ------- | ------- | ------- | 1.3 | 6.9 | 14.6 | 20.8 | 24.4 | 24.2 | 20.6 | 15.0 | 7.6 | 1.4 | ------- | ------- | ------- |
| Dec. 24 [1] | ------- | ------- | ------- | 1.3 | 7.3 | 15.0 | 20.9 | 23.5 | 24.5 | 21.2 | 15.5 | 8.1 | 1.8 | ------- | ------- | ------- |
| Means | .1 | 1.5 | 6.0 | 14.6 | 24.7 | 35.0 | 42.0 | 45.8 | 45.8 | 42.1 | 35.1 | 25.3 | 15.0 | 6.4 | 1.6 | .1 |

[1] 8-day period.

TABLE 4.—*Ratio of direct solar radiation on a horizontal surface to diffuse sky radiation during cloudless days, Washington, D. C.*

| Solar zenith distance | 30° | 60° | 78.7° |
|---|---|---|---|
| Air mass | 1.15 | 2.0 | 5.0 |
| Winter | 8.1 | 5.0 | 1.7 |
| Summer | 5.2 | 3.1 | 1.5 |
| Mean | 6.65 | 4.05 | 1.6 |

TABLE 5.—*Monthly mean intensities of direct solar radiation at normal incidence, gram calories per square centimeter per minute*

[Lines (1) and (2) are the a. m. and p. m. intensities, respectively, at the given air masses, and line (3) is their average; line (4) is the average reduced to mean solar distance, and line (5) its expression as a percentage of the solar constant; (6) is the atmospheric transmission computed by equation (1) in the text]

WASHINGTON, D. C., OCTOBER 1914 TO DECEMBER 1936, INCLUSIVE

| Air mass | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | Air mass | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| January: | | | | | | July: | | | | | |
| (1) | | 1.24 | 1.02 | 0.86 | 0.75 | (1) | 1.21 | 0.92 | 0.78 | 0.68 | 0.58 |
| (2) | | 1.24 | 1.05 | .90 | .81 | (2) | | 1.00 | .79 | .68 | (.75) |
| (3) | | 1.24 | 1.03 | .88 | .77 | (3) | 1.21 | .93 | .78 | .68 | .59 |
| (4) | | 1.20 | 1.00 | .85 | .75 | (4) | 1.25 | .96 | .80 | .70 | .61 |
| (5) | | 62 | 51 | 44 | 39 | (5) | 64 | 49 | 41 | 36 | 31 |
| (6) | | .786 | .800 | .814 | .826 | (6) | .661 | .704 | .746 | .773 | .793 |
| February: | | | | | | August: | | | | | |
| (1) | 1.56 | 1.20 | 1.00 | .83 | .73 | (1) | 1.25 | .94 | .77 | .69 | .63 |
| (2) | | 1.20 | 1.00 | .86 | .77 | (2) | | 1.03 | .87 | .73 | .63 |
| (3) | 1.56 | 1.20 | 1.00 | .84 | .74 | (3) | 1.25 | .96 | .79 | .70 | .63 |
| (4) | 1.53 | 1.17 | .98 | .82 | .72 | (4) | 1.28 | .98 | .81 | .72 | .65 |
| (5) | 79 | 60 | 51 | 42 | 37 | (5) | 66 | 51 | 42 | 37 | 34 |
| (6) | .784 | .777 | .795 | .806 | .821 | (6) | .677 | .720 | .754 | .785 | .803 |
| March: | | | | | | September: | | | | | |
| (1) | 1.42 | 1.15 | .95 | .81 | .73 | (1) | 1.31 | 1.04 | .86 | .75 | .69 |
| (2) | | 1.13 | .94 | .79 | .70 | (2) | | 1.07 | .87 | .75 | .69 |
| (3) | 1.42 | 1.15 | .95 | .80 | .72 | (3) | 1.31 | 1.05 | .86 | .75 | .69 |
| (4) | 1.41 | 1.14 | .94 | .79 | .71 | (4) | 1.32 | 1.06 | .87 | .76 | .70 |
| (5) | 73 | 59 | 48 | 41 | 37 | (5) | 68 | 55 | 45 | 39 | 36 |
| (6) | .724 | .766 | .785 | .799 | .818 | (6) | .682 | .740 | .765 | .791 | .815 |
| April: | | | | | | October: | | | | | |
| (1) | 1.36 | 1.08 | .89 | .79 | .69 | (1) | 1.42 | 1.13 | .97 | .85 | .75 |
| (2) | | 1.09 | .89 | .74 | .63 | (2) | | 1.13 | .95 | .82 | .74 |
| (3) | 1.36 | 1.09 | .89 | .77 | .63 | (3) | 1.42 | 1.13 | .96 | .84 | .75 |
| (4) | 1.37 | 1.09 | .90 | .78 | .69 | (4) | 1.41 | 1.12 | .95 | .83 | .74 |
| (5) | 71 | 56 | 46 | 40 | 36 | (5) | 73 | 58 | 49 | 43 | 38 |
| (6) | .711 | .753 | .776 | .798 | 8.14 | (6) | .728 | .761 | .79 | .810 | .826 |
| May: | | | | | | November: | | | | | |
| (1) | 1.27 | 1.00 | .83 | .72 | .63 | (1) | 1.48 | 1.19 | 1.01 | .87 | .75 |
| (2) | | .93 | .88 | .66 | .58 | (2) | | 1.18 | 1.00 | .85 | .74 |
| (3) | 1.27 | .99 | .82 | .71 | .63 | (3) | 1.48 | 1.18 | 1.00 | .86 | .75 |
| (4) | 1.30 | 1.01 | .84 | .72 | .64 | (4) | 1.45 | 1.16 | .98 | .84 | .74 |
| (5) | 67 | 52 | 43 | 37 | 33 | (5) | 75 | 60 | 51 | 43 | 38 |
| (6) | .669 | .722 | .756 | .782 | .802 | (6) | .746 | .771 | .796 | .811 | .821 |
| June: | | | | | | December: | | | | | |
| (1) | 1.25 | .94 | .78 | .67 | .54 | (1) | 1.51 | 1.23 | 1.05 | .90 | .78 |
| (2) | | .94 | .72 | .66 | | (2) | | 1.29 | 1.04 | .91 | .79 |
| (3) | 1.25 | .94 | .78 | .67 | .54 | (3) | 1.51 | 1.23 | 1.04 | .91 | .79 |
| (4) | 1.29 | .97 | .80 | .69 | .56 | (4) | 1.46 | 1.19 | 1.01 | .89 | .76 |
| (5) | 67 | 50 | 41 | 36 | 29 | (5) | 75 | 61 | 52 | 46 | 39 |
| (6) | .665 | .707 | .746 | .778 | .785 | (6) | .754 | .784 | .809 | .817 | .830 |

MADISON, WIS., JULY 1910 TO DECEMBER 1936, INCLUSIVE

| Air mass | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | Air mass | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| January: | | | | | | July: | | | | | |
| (1) | 1.56 | 1.36 | 1.21 | 1.06 | 0.96 | (1) | 1.31 | 1.07 | 0.92 | 0.78 | 0.67 |
| (2) | | 1.42 | 1.15 | 1.07 | | (2) | | 1.04 | .91 | .78 | |
| (3) | 1.56 | 1.36 | 1.17 | 1.06 | .96 | (3) | 1.31 | 1.06 | .92 | .78 | .67 |
| (4) | 1.51 | 1.32 | 1.13 | 1.02 | .94 | (4) | 1.35 | 1.09 | .95 | .80 | .69 |
| (5) | 79 | 69 | 59 | 54 | 48 | (5) | 70 | 56 | 49 | 41 | 36 |
| (6) | .778 | .824 | .836 | .853 | .863 | (6) | .698 | .751 | .788 | .803 | .814 |
| February: | | | | | | August: | | | | | |
| (1) | 1.58 | 1.36 | 1.20 | 1.07 | .93 | (1) | 1.32 | 1.09 | .97 | .81 | .71 |
| (2) | | 1.36 | 1.17 | 1.12 | (1.11) | (2) | | 1.05 | .87 | .82 | .61 |
| (3) | 1.58 | 1.36 | 1.19 | 1.07 | .94 | (3) | 1.32 | 1.08 | .93 | .81 | .69 |
| (4) | 1.54 | 1.33 | 1.16 | 1.04 | .92 | (4) | 1.35 | 1.11 | .95 | .83 | .70 |
| (5) | 79 | 69 | 60 | 54 | 47 | (5) | 70 | 57 | 49 | 43 | 36 |
| (6) | .794 | .827 | .843 | .856 | .861 | (6) | .698 | .756 | .789 | .804 | .817 |
| March: | | | | | | September: | | | | | |
| (1) | 1.58 | 1.31 | 1.16 | 1.02 | .92 | (1) | 1.40 | 1.16 | 1.03 | .91 | .84 |
| (2) | | 1.29 | 1.17 | 1.07 | .93 | (2) | | 1.18 | 1.03 | .85 | .89 |
| (3) | 1.58 | 1.30 | 1.16 | 1.03 | .92 | (3) | 1.40 | 1.17 | 1.03 | .90 | .84 |
| (4) | 1.56 | 1.29 | 1.14 | 1.02 | .91 | (4) | 1.41 | 1.18 | 1.04 | .91 | .85 |
| (5) | 80 | 66 | 59 | 53 | 47 | (5) | 73 | 61 | 54 | 47 | 44 |
| (6) | .806 | .814 | .839 | .851 | .859 | (6) | .729 | .780 | .813 | .827 | .848 |
| April: | | | | | | October: | | | | | |
| (1) | 1.44 | 1.19 | 1.03 | .91 | .84 | (1) | 1.43 | 1.20 | 1.05 | .92 | .80 |
| (2) | | 1.18 | 1.08 | .87 | .68 | (2) | | 1.20 | 1.02 | .90 | .64 |
| (3) | 1.44 | 1.19 | 1.04 | .91 | .79 | (3) | 1.43 | 1.20 | 1.05 | .92 | .78 |
| (4) | 1.46 | 1.20 | 1.05 | .92 | .80 | (4) | 1.42 | 1.19 | 1.04 | .91 | .77 |
| (5) | 75 | 62 | 54 | 47 | 41 | (5) | 73 | 61 | 54 | 47 | 40 |
| (6) | .747 | .786 | .814 | .829 | .837 | (6) | .733 | .784 | .814 | .829 | .833 |
| May: | | | | | | November: | | | | | |
| (1) | 1.37 | 1.11 | 1.01 | .82 | .80 | (1) | 1.54 | 1.31 | 1.16 | 1.00 | .89 |
| (2) | | 1.04 | .89 | | | (2) | | 1.33 | 1.12 | .84 | (.24) |
| (3) | 1.37 | 1.10 | 1.00 | .82 | .79 | (3) | 1.54 | 1.31 | 1.14 | 1.00 | .88 |
| (4) | 1.40 | 1.12 | 1.02 | .84 | .81 | (4) | 1.51 | 1.29 | 1.12 | .98 | .86 |
| (5) | 72 | 58 | 53 | 43 | 42 | (5) | 78 | 66 | 58 | 51 | 44 |
| (6) | .722 | .761 | .808 | .811 | .839 | (6) | .777 | .813 | .831 | .843 | .850 |
| June: | | | | | | December: | | | | | |
| (1) | 1.33 | 1.04 | .98 | .86 | .76 | (1) | 1.52 | 1.36 | 1.21 | 1.08 | .96 |
| (2) | | 1.09 | .92 | | | (2) | | | 1.25 | 1.02 | |
| (3) | 1.33 | 1.05 | .98 | .86 | .76 | (3) | 1.52 | 1.36 | 1.22 | 1.07 | .96 |
| (4) | 1.37 | 1.08 | 1.01 | .89 | .78 | (4) | 1.47 | 1.32 | 1.18 | 1.04 | .93 |
| (5) | 71 | 56 | 52 | 46 | 40 | (5) | 76 | 68 | 61 | 54 | 48 |
| (6) | .707 | .747 | .805 | .822 | .834 | (6) | .759 | .824 | .848 | .855 | .863 |

TABLE 5.—*Monthly mean intensities of direct solar radiation at normal incidence, gram calories per square centimeter per minute*—Continued

[Lines (1) and (2) are the a. m. and p. m. intensities, respectively, at the given air masses, and line (3) is their average; line (4) is the average reduced to mean solar distance, and line (5) its expression as a percentage of the solar constant; (6) is the atmospheric transmission computed by equation (1) in the text]

LINCOLN, NEBR., NOVEMBER 1911 TO DECEMBER 1936, INCLUSIVE

| Air mass | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | Air mass | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| January: | | | | | | July: | | | | | |
| (1) | | 1.38 | 1.19 | 1.05 | 0.93 | (1) | 1.34 | 1.08 | 0.92 | 0.79 | 0.71 |
| (2) | | 1.35 | 1.18 | 1.05 | .93 | (2) | | 1.07 | .89 | .76 | .70 |
| (3) | | 1.37 | 1.18 | 1.05 | .93 | (3) | 1.34 | 1.08 | .90 | .77 | .70 |
| (4) | | 1.32 | 1.14 | 1.01 | .90 | (4) | 1.38 | 1.11 | .93 | .79 | .72 |
| (5) | | 70 | 60 | 53 | 47 | (5) | 71 | 57 | 48 | 41 | 37 |
| (6) | | .827 | .838 | .851 | .856 | (6) | .714 | .758 | .783 | .800 | .836 |
| February: | | | | | | August: | | | | | |
| (1) | 1.54 | 1.37 | 1.16 | 1.02 | .93 | (1) | 1.31 | 1.09 | .91 | .78 | .68 |
| (2) | | 1.35 | 1.16 | 1.02 | .90 | (2) | | 1.07 | .89 | .75 | .64 |
| (3) | 1.54 | 1.36 | 1.16 | 1.02 | .92 | (3) | 1.31 | 1.09 | .90 | .77 | .66 |
| (4) | 1.50 | 1.33 | 1.13 | 1.00 | .90 | (4) | 1.34 | 1.11 | .92 | .79 | .68 |
| (5) | 77 | 69 | 59 | 52 | 46 | (5) | 69 | 57 | 47 | 41 | 35 |
| (6) | .774 | .827 | .836 | .846 | .857 | (6) | .693 | .760 | .781 | .799 | .810 |
| March: | | | | | | September: | | | | | |
| (1) | 1.53 | 1.28 | 1.09 | .94 | .84 | (1) | 1.42 | 1.13 | .97 | .84 | .74 |
| (2) | | 1.28 | 1.09 | .94 | .81 | (2) | | 1.16 | .98 | .84 | .73 |
| (3) | 1.53 | 1.28 | 1.09 | .94 | .82 | (3) | 1.42 | 1.14 | .97 | .84 | .74 |
| (4) | 1.51 | 1.27 | 1.08 | .93 | .81 | (4) | 1.43 | 1.15 | .98 | .85 | .75 |
| (5) | 78 | 65 | 56 | 48 | 42 | (5) | 74 | 59 | 51 | 44 | 39 |
| (6) | .775 | .808 | .822 | .832 | .838 | (6) | .740 | .771 | .796 | .813 | .823 |
| April: | | | | | | October: | | | | | |
| (1) | 1.45 | 1.19 | .97 | .82 | .71 | (1) | 1.48 | 1.29 | 1.09 | .93 | .83 |
| (2) | | 1.16 | .96 | .82 | .69 | (2) | | 1.25 | 1.08 | .94 | .83 |
| (3) | 1.45 | 1.18 | .97 | .82 | .70 | (3) | 1.48 | 1.27 | 1.09 | .94 | .83 |
| (4) | 1.46 | 1.19 | .98 | .83 | .71 | (4) | 1.47 | 1.26 | 1.08 | .93 | .82 |
| (5) | 75 | 61 | 51 | 43 | 37 | (5) | 76 | 65 | 56 | 48 | 42 |
| (6) | .753 | .783 | .796 | .808 | .817 | (6) | .759 | .807 | .824 | .832 | .843 |
| May: | | | | | | November: | | | | | |
| (1) | 1.38 | 1.11 | .93 | .78 | .66 | (1) | 1.55 | 1.35 | 1.18 | 1.03 | .92 |
| (2) | | 1.10 | .90 | .81 | .68 | (2) | | 1.35 | 1.18 | 1.04 | .92 |
| (3) | 1.38 | 1.11 | .92 | .79 | .67 | (3) | 1.55 | 1.35 | 1.18 | 1.03 | .92 |
| (4) | 1.41 | 1.13 | .94 | .81 | .69 | (4) | 1.52 | 1.32 | 1.16 | 1.01 | .90 |
| (5) | 73 | 58 | 48 | 42 | 36 | (5) | 78 | 67 | 60 | 52 | 46 |
| (6) | .727 | .765 | .786 | .803 | .812 | (6) | .782 | .825 | .841 | .849 | .858 |
| June: | | | | | | December: | | | | | |
| (1) | 1.36 | 1.11 | .94 | .79 | .76 | (1) | 1.64 | 1.38 | 1.23 | 1.09 | .94 |
| (2) | | 1.11 | .92 | .79 | .68 | (2) | | | 1.20 | 1.07 | .96 |
| (3) | 1.36 | 1.11 | .93 | .79 | .71 | (3) | 1.64 | 1.38 | 1.22 | 1.08 | .95 |
| (4) | 1.40 | 1.14 | .96 | .81 | .73 | (4) | 1.59 | 1.34 | 1.18 | 1.05 | .92 |
| (5) | 72 | 59 | 49 | 42 | 38 | (5) | 82 | 69 | 61 | 54 | 47 |
| (6) | .723 | .768 | .791 | .805 | .823 | (6) | .819 | .830 | .848 | .857 | .861 |

BLUE HILL, MASS., SEPTEMBER 1933 TO DECEMBER 1936, INCLUSIVE

| Air mass | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | Air mass | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| January: | | | | | | July: | | | | | |
| (1) | | 1.32 | 1.14 | 1.02 | 0.90 | (1) | 1.28 | 1.06 | 0.98 | 0.85 | 0.76 |
| (2) | | 1.34 | 1.18 | 1.09 | .98 | (2) | | 1.03 | .95 | .84 | .76 |
| (3) | | 1.32 | 1.16 | 1.05 | .94 | (3) | 1.28 | 1.06 | .98 | .85 | .76 |
| (4) | | 1.28 | 1.12 | 1.02 | .91 | (4) | 1.32 | 1.09 | 1.01 | .88 | .78 |
| (5) | | 66 | 58 | 53 | 47 | (5) | 68 | 56 | 52 | 46 | 40 |
| (6) | | .811 | .833 | .851 | .859 | (6) | .682 | .751 | .805 | .820 | .835 |
| February: | | | | | | August: | | | | | |
| (1) | 1.47 | 1.26 | 1.06 | .98 | .85 | (1) | 1.26 | 1.08 | .95 | .83 | .70 |
| (2) | | 1.26 | 1.14 | 1.06 | 1.00 | (2) | | 1.09 | .96 | .72 | .68 |
| (3) | 1.47 | 1.26 | 1.10 | 1.03 | .94 | (3) | 1.26 | 1.06 | .96 | .77 | .68 |
| (4) | 1.44 | 1.23 | 1.08 | 1.01 | .92 | (4) | 1.29 | 1.09 | .98 | .79 | .70 |
| (5) | 74 | 64 | 56 | 52 | 47 | (5) | 66 | 56 | 51 | 41 | 35 |
| (6) | .739 | .796 | .821 | .848 | .861 | (6) | .666 | .749 | .798 | .799 | .815 |
| March: | | | | | | September: | | | | | |
| (1) | 1.40 | 1.19 | 1.03 | .93 | .82 | (1) | 1.36 | 1.17 | 1.04 | .95 | .82 |
| (2) | | 1.18 | 1.00 | .93 | .81 | (2) | | 1.13 | .93 | .84 | .75 |
| (3) | 1.40 | 1.19 | 1.03 | .93 | .82 | (3) | 1.36 | 1.15 | 1.00 | .91 | .78 |
| (4) | 1.39 | 1.18 | 1.02 | .92 | .81 | (4) | 1.37 | 1.16 | 1.01 | .92 | .79 |
| (5) | 72 | 60 | 53 | 47 | 42 | (5) | 71 | 60 | 52 | 47 | 41 |
| (6) | .714 | .779 | .806 | .830 | .840 | (6) | .708 | .774 | .805 | .830 | .835 |
| April: | | | | | | October: | | | | | |
| (1) | 1.40 | 1.16 | 1.10 | .94 | .86 | (1) | 1.42 | 1.26 | 1.14 | 1.03 | 1.00 |
| (2) | | 1.10 | 1.00 | .95 | (.85) | (2) | | 1.22 | 1.03 | .89 | .75 |
| (3) | 1.40 | 1.14 | 1.04 | .94 | .86 | (3) | 1.42 | 1.24 | 1.08 | .96 | .89 |
| (4) | 1.41 | 1.15 | 1.05 | .95 | .87 | (4) | 1.41 | 1.23 | 1.07 | .95 | .88 |
| (5) | 73 | 59 | 54 | 49 | 45 | (5) | 73 | 63 | 55 | 49 | 45 |
| (6) | .726 | .769 | .814 | .836 | .851 | (6) | .728 | .797 | .821 | .838 | .855 |
| May: | | | | | | November: | | | | | |
| (1) | 1.37 | 1.13 | 1.11 | 1.00 | .94 | (1) | | 1.27 | 1.15 | 1.08 | 1.01 |
| (2) | | 1.10 | .89 | .80 | (.88) | (2) | | 1.27 | 1.14 | .98 | .79 |
| (3) | 1.37 | 1.12 | 1.03 | .94 | .91 | (3) | | 1.27 | 1.14 | 1.03 | .91 |
| (4) | 1.40 | 1.14 | 1.05 | .96 | .93 | (4) | | 1.24 | 1.11 | 1.01 | .89 |
| (5) | 72 | 59 | 54 | 49 | 48 | (5) | | 64 | 57 | 52 | 46 |
| (6) | .720 | .768 | .815 | .839 | .863 | (6) | | .799 | .831 | .848 | .856 |
| June: | | | | | | December: | | | | | |
| (1) | 1.29 | 1.08 | 1.03 | .86 | | (1) | | 1.39 | 1.20 | 1.11 | .95 |
| (2) | | 1.07 | .90 | .88 | .77 | (2) | | 1.30 | 1.19 | 1.04 | .95 |
| (3) | 1.29 | 1.07 | .96 | .88 | .77 | (3) | | 1.35 | 1.19 | 1.07 | .95 |
| (4) | 1.33 | 1.10 | .99 | .91 | .79 | (4) | | 1.31 | 1.15 | 1.04 | .92 |
| (5) | 69 | 57 | 51 | 47 | 41 | (5) | | 68 | 59 | 54 | 47 |
| (6) | .686 | .758 | .799 | .827 | .836 | (6) | | .821 | .841 | .855 | .862 |

TABLE 6.—*Values of the air mass, m, at different altitudes, h, of the sun, computed by Bemporad's formula*

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| h | 90° | 80° | 75° | 70° | 69° | 68° | 67° | 66° | 65° | 64° |
| m | 1.00 | 1.02 | 1.04 | 1.06 | 1.07 | 1.08 | 1.09 | 1.09 | 1.10 | 1.11 |
| h | 63° | 62° | 61° | 60° | 59° | 58° | 57° | 56° | 55° | 54° |
| m | 1.12 | 1.13 | 1.14 | 1.15 | 1.17 | 1.18 | 1.19 | 1.20 | 1.22 | 1.24 |
| h | 53° | 52° | 51° | 50° | 49° | 48° | 47° | 46° | 45° | 44° |
| m | 1.25 | 1.27 | 1.28 | 1.30 | 1.32 | 1.34 | 1.37 | 1.39 | 1.41 | 1.44 |
| h | 43° | 42° | 41° | 40° | 39° | 38° | 37° | 36° | 35° | 34° |
| ′ ′ ° | | | | | | | | | | |
| 52–57=0.9 | 1.44 | 1.47 | 1.49 | 1.53 | 1.56 | 1.59 | 1.62 | 1.66 | 1.70 | 1.74 |
| 46–51=0.8 | 1.44 | 1.47 | 1.50 | 1.53 | 1.56 | 1.59 | 1.63 | 1.67 | 1.71 | 1.75 |
| 40–45=0.7 | 1.45 | 1.47 | 1.50 | 1.53 | 1.56 | 1.60 | 1.63 | 1.67 | 1.71 | 1.75 |
| 34–39=0.6 | 1.45 | 1.48 | 1.50 | 1.53 | 1.57 | 1.60 | 1.63 | 1.67 | 1.71 | 1.76 |
| 28–33=0.5 | 1.45 | 1.48 | 1.51 | 1.54 | 1.57 | 1.60 | 1.64 | 1.68 | 1.72 | 1.76 |
| 22–27=0.4 | 1.45 | 1.48 | 1.51 | 1.54 | 1.57 | 1.61 | 1.64 | 1.68 | 1.72 | 1.77 |
| 16–21=0.3 | 1.46 | 1.48 | 1.51 | 1.54 | 1.58 | 1.61 | 1.65 | 1.69 | 1.73 | 1.77 |
| 10–15=0.2 | 1.46 | 1.49 | 1.52 | 1.55 | 1.58 | 1.61 | 1.65 | 1.69 | 1.73 | 1.78 |
| 4– 9=0.1 | 1.46 | 1.49 | 1.52 | 1.55 | 1.58 | 1.62 | 1.65 | 1.69 | 1.74 | 1.78 |
| 57– 3=0.0 | 1.46 | 1.49 | 1.52 | 1.55 | 1.59 | 1.62 | 1.66 | 1.70 | 1.74 | 1.78 |
| h | 33° | 32° | 31° | 30° | 29° | 28° | 27° | 26° | 25° | 24° |
| ′ ′ ° | | | | | | | | | | |
| 52–57=0.9 | 1.79 | 1.84 | 1.89 | 1.94 | 2.00 | 2.06 | 2.13 | 2.20 | 2.28 | 2.36 |
| 46–51=0.8 | 1.79 | 1.84 | 1.89 | 1.95 | 2.01 | 2.07 | 2.14 | 2.21 | 2.29 | 2.37 |
| 40–45=0.7 | 1.80 | 1.85 | 1.90 | 1.95 | 2.01 | 2.08 | 2.14 | 2.22 | 2.30 | 2.38 |
| 34–39=0.6 | 1.80 | 1.86 | 1.90 | 1.96 | 2.02 | 2.08 | 2.15 | 2.23 | 2.31 | 2.39 |
| 28–33=0.5 | 1.81 | 1.86 | 1.91 | 1.96 | 2.02 | 2.09 | 2.16 | 2.24 | 2.32 | 2.40 |
| 22–27=0.4 | 1.81 | 1.87 | 1.92 | 1.97 | 2.03 | 2.10 | 2.17 | 2.25 | 2.33 | 2.41 |
| 16–21=0.3 | 1.82 | 1.87 | 1.92 | 1.98 | 2.04 | 2.10 | 2.17 | 2.25 | 2.33 | 2.42 |
| 10–15=0.2 | 1.82 | 1.87 | 1.93 | 1.98 | 2.05 | 2.11 | 2.18 | 2.26 | 2.34 | 2.43 |
| 3– 9=0.1 | 1.83 | 1.88 | 1.93 | 1.99 | 2.06 | 2.12 | 2.19 | 2.27 | 2.35 | 2.44 |
| 57– 3=0.0 | 1.83 | 1.88 | 1.94 | 2.00 | 2.06 | 2.12 | 2.20 | 2.28 | 2.36 | 2.45 |
| h | 23° | 22° | 21° | 20° | 19° | 18° | 17° | 16° | 15° | 14° |
| ′ ′ ° | | | | | | | | | | |
| 52–57=0.9 | 2.46 | 2.56 | 2.66 | 2.78 | 2.92 | 3.06 | 3.23 | 3.41 | 3.61 | 3.84 |
| 46–51=0.8 | 2.47 | 2.57 | 2.68 | 2.80 | 2.93 | 3.08 | 3.24 | 3.43 | 3.63 | 3.86 |
| 40–45=0.7 | 2.48 | 2.58 | 2.69 | 2.81 | 2.95 | 3.10 | 3.26 | 3.45 | 3.65 | 3.89 |
| 34–39=0.6 | 2.49 | 2.59 | 2.70 | 2.82 | 2.96 | 3.11 | 3.28 | 3.47 | 3.68 | 3.92 |
| 28–33=0.5 | 2.50 | 2.60 | 2.71 | 2.84 | 2.98 | 3.13 | 3.30 | 3.49 | 3.70 | 3.94 |
| 22–27=0.4 | 2.51 | 2.61 | 2.72 | 2.85 | 2.99 | 3.14 | 3.31 | 3.51 | 3.72 | 3.97 |
| 16–21=0.3 | 2.52 | 2.62 | 2.74 | 2.86 | 3.00 | 3.16 | 3.33 | 3.53 | 3.74 | 3.99 |
| 10–15=0.2 | 2.53 | 2.63 | 2.75 | 2.88 | 3.02 | 3.18 | 3.35 | 3.55 | 2.77 | 4.02 |
| 4– 9=0.1 | 2.54 | 2.64 | 2.76 | 2.89 | 3.03 | 3.19 | 3.37 | 3.57 | 3.79 | 4.05 |
| 57– 3=0.0 | 2.55 | 2.65 | 2.77 | 2.90 | 3.05 | 3.21 | 3.39 | 3.59 | 3.82 | 4.08 |
| h | 13° | 12° | 11° | 10° | 9° | | | | | |
| ′ ′ ° | | | | | | | | | | |
| 52–57=0.9 | 4.10 | 4.40 | 4.75 | 5.16 | 5.64 | | | | | |
| 46–51=0.8 | 4.13 | 4.44 | 4.79 | 5.21 | 5.70 | | | | | |
| 40–45=0.7 | 4.16 | 4.47 | 4.83 | 5.26 | 5.76 | | | | | |
| 34–39=0.6 | 4.19 | 4.50 | 4.87 | 5.30 | 5.82 | | | | | |
| 28–33=0.5 | 4.22 | 4.54 | 4.91 | 5.35 | 5.87 | | | | | |
| 22–27=0.4 | 4.25 | 4.57 | 4.95 | 5.40 | 5.93 | | | | | |
| 16–21=0.3 | 4.28 | 4.61 | 4.99 | 5.45 | 5.99 | | | | | |
| 10–15=0.2 | 4.31 | 4.64 | 5.03 | 5.50 | 6.06 | | | | | |
| 4– 9=0.1 | 4.34 | 4.68 | 5.08 | 5.55 | 6.12 | | | | | |
| 57– 3=0.0 | 4.37 | 4.72 | 5.12 | 5.60 | 6.19 | | | | | |

TABLE 7.—*Maximum observed normal incidence intensities, gram calories per square centimeter per minute*

| Month | Washington | | Madison | | Lincoln | | Santa Fe | | Mount Weather | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Observed | Reduced[1] | Observed | Reduced[1] | Observed | Reduced[1] | Observed | Reduced[1] | Observed | Reduced[1] |
| January | 1.45 | 1.41 | 1.56 | 1.44 | 1.53 | 1.48 | 1.66 | 1.61 | 1.37 | 1.32 |
| February | 1.59 | 1.55 | 1.57 | 1.54 | 1.58 | 1.54 | 1.65 | 1.62 | 1.48 | 1.45 |
| March | 1.53 | 1.50 | 1.50 | 1.57 | 1.56 | 1.54 | 1.66 | 1.63 | 1.48 | 1.46 |
| April | 1.51 | 1.52 | 1.58 | 1.58 | 1.58 | 1.59 | 1.64 | 1.64 | 1.45 | 1.46 |
| May | 1.46 | 1.50 | 1.49 | 1.52 | 1.53 | 1.56 | 1.61 | 1.63 | 1.50 | 1.53 |
| June | 1.47 | 1.52 | 1.45 | 1.49 | 1.49 | 1.53 | 1.57 | 1.62 | 1.47 | 1.52 |
| July | 1.47 | 1.52 | 1.46 | 1.50 | 1.44 | 1.49 | 1.45 | 1.50 | 1.48 | 1.53 |
| August | 1.43 | 1.47 | 1.46 | 1.50 | 1.49 | 1.53 | 1.56 | 1.59 | 1.45 | 1.48 |
| September | 1.49 | 1.51 | 1.46 | 1.48 | 1.48 | 1.49 | 1.62 | 1.63 | 1.50 | 1.51 |
| October | 1.51 | 1.51 | 1.46 | 1.45 | 1.53 | 1.52 | 1.59 | 1.58 | 1.48 | 1.47 |
| November | 1.49 | 1.45 | 1.42 | 1.40 | 1.56 | 1.53 | 1.63 | 1.60 | 1.43 | 1.40 |
| December | 1.48 | 1.43 | 1.47 | 1.42 | 1.51 | 1.46 | 1.61 | 1.56 | 1.40 | 1.36 |
| Year | 1.49 | 1.49 | 1.50 | 1.49 | 1.54 | 1.54 | 1.60 | 1.60 | 1.50 | 1.54 |
| Range | .16 | .14 | .18 | .18 | .14 | .13 | .11 | .14 | .13 | .12 |

[1] To mean solar distance.

TABLE 8.—*Illumination equivalent of 1 gram calorie per minute per square centimeter of total solar and sky radiation at different solar altitudes*

| Air mass | 1.06 | 1.1 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 | 5.5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Solar altitude | 70.0° | 65.0° | 42.7° | 30.0° | 23.5° | 19.3° | 16.4° | 14.3° | 12.6° | 11.3° | 10.2° |
| MOUNT WEATHER, VA. (1919) | | | | | | | | | | | |
| Foot candles | ------ | 6,720 | 6,600 | 5,580 | 5,310 | 5,120 | 4,780 | 4,670 | 4,610 | 4,600 | 4,480 |
| WASHINGTON, D. C. (1921–22) | | | | | | | | | | | |
| Foot candles | 7,040 | 7,020 | 6,880 | 6,740 | 6,650 | 6,580 | 6,520 | 6,460 | 6,410 | 6,370 | 6,320 |

TABLE 9.—*Sky polarization, percent, sun at zenith distance 60°, Washington, D. C.*

(Average of values observed during month)

| Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1914 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 65 | 62 |
| 1915 | 63 | ----- | 65 | 57 | 50 | 52 | 45 | 45 | 54 | 64 | 62 | 60 |
| 1916 | 64 | 61 | 64 | 52 | 51 | 46 | 54 | 50 | 56 | 56 | 54 | 58 |
| 1917 | 61 | 65 | 60 | 48 | 48 | 44 | 40 | 50 | 59 | 51 | 50 | 51 |
| 1918 | ----- | 47 | 54 | 60 | 52 | 46 | 55 | 56 | 56 | 60 | 59 | 58 |
| 1919 | 55 | 53 | 62 | 56 | ----- | 39 | 48 | 50 | 59 | 55 | 53 | 62 |
| 1920 | 56 | 48 | 53 | 54 | 57 | 48 | 51 | ----- | 58 | 56 | 63 | 60 |
| 1921 | 59 | 64 | 54 | 44 | 56 | 52 | 38 | 54 | 54 | 63 | 64 | 55 |
| 1922 | 57 | 55 | 56 | 56 | 60 | 44 | 50 | 57 | 57 | 57 | 60 | 58 |
| 1923 | 66 | 63 | 56 | 52 | 51 | 40 | 50 | 47 | 57 | 56 | 60 | 64 |
| 1924 | 56 | 58 | 55 | 58 | 49 | 38 | 51 | 56 | 50 | 62 | 62 | 55 |
| 1925 | ----- | 51 | 56 | 60 | 48 | 49 | 43 | 51 | 55 | 64 | 63 | 64 |
| 1926 | ----- | 58 | 61 | 65 | 60 | 53 | 53 | 54 | 51 | 57 | 62 | 65 |
| 1927 | 63 | 61 | 54 | 54 | 56 | 57 | 56 | 44 | 57 | 55 | 57 | 52 |
| 1928 | 57 | 59 | 60 | 57 | 54 | 50 | 46 | 52 | 52 | 50 | 62 | 56 |
| 1929 | 58 | 63 | 62 | 58 | 51 | 48 | 53 | 54 | 51 | 53 | 52 | 52 |
| 1930 | ----- | 63 | 58 | 46 | 53 | 54 | 51 | 57 | 50 | 52 | 52 | 59 |
| 1931 | 56 | 61 | 56 | 59 | 56 | 59 | 53 | 54 | 56 | 63 | 60 | 61 |
| 1932 | 62 | ----- | 58 | 58 | 54 | 60 | 62 | 60 | 57 | 60 | 58 | 55 |
| 1933 | 58 | 52 | 49 | 54 | 55 | 46 | 57 | 57 | 56 | 59 | 57 | 60 |
| 1934 | 61 | ----- | 61 | 57 | 46 | 56 | 55 | 58 | 54 | 54 | 54 | 54 |
| 1935 | 55 | 56 | 59 | 59 | 60 | 58 | 56 | ----- | 58 | 59 | 58 | 57 |
| 1936 | ----- | ----- | 60 | 61 | 61 | 61 | 56 | 58 | 55 | 61 | 55 | 55 |
| Mean | 59.5 | 59.2 | 57.9 | 55.7 | 53.7 | 50.0 | 51.0 | 53.4 | 55.1 | 57.6 | 58.3 | 59.6 |

MAXIMUM VALUE OBSERVED DURING MONTH[1]

| Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1914 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 72 | 69 |
| 1915 | 68 | ----- | 71 | 67 | 53 | 63 | 57 | 49 | 72 | 69 | 66 | 66 |
| 1916 | 66 | 65 | 70 | 58 | 58 | 59 | 64 | 66 | 65 | 61 | 59 | 63 |
| 1917 | 66 | 69 | 65 | 66 | 62 | 50 | 49 | 56 | 66 | 63 | 60 | 52 |
| 1918 | ----- | 65 | 64 | 66 | 59 | 47 | 64 | 62 | 62 | 64 | 64 | 62 |
| 1919 | 60 | 65 | 66 | 64 | ----- | 43 | 59 | 65 | 67 | 63 | 66 | 66 |
| 1920 | 63 | 52 | 65 | 59 | 64 | 54 | 57 | ----- | 67 | 64 | 65 | 60 |
| 1921 | 65 | 64 | 64 | 63 | 63 | 59 | 51 | 61 | 69 | 72 | 65 | 65 |
| 1922 | 62 | 57 | 62 | 59 | 63 | 51 | 61 | 70 | 65 | 74 | 63 | 64 |
| 1923 | 66 | 70 | 63 | 64 | 67 | 56 | 59 | 58 | 70 | 67 | 70 | 64 |
| 1924 | 67 | 65 | 63 | 62 | 56 | 55 | 69 | 64 | 52 | 68 | 64 | 56 |
| 1925 | ----- | 58 | 65 | 66 | 56 | 60 | 49 | 56 | 67 | 71 | 66 | 69 |
| 1926 | ----- | 60 | 66 | 66 | 65 | 56 | 56 | 58 | ----- | 60 | 67 | 66 |
| 1927 | 65 | 62 | 68 | 60 | 56 | 59 | 57 | 47 | 66 | 57 | 57 | 57 |
| 1928 | 61 | 63 | 63 | 59 | 63 | 56 | 48 | 54 | 55 | 56 | 67 | 60 |
| 1929 | 59 | 64 | 68 | 62 | 60 | 52 | 61 | 58 | 56 | 66 | 55 | 64 |
| 1930 | ----- | 66 | 61 | 60 | 62 | 56 | 60 | 62 | 47 | 55 | 52 | 62 |
| 1931 | 59 | 64 | 60 | 66 | 58 | 64 | 58 | 54 | 64 | 70 | 66 | 65 |
| 1932 | 66 | ----- | 64 | 63 | 59 | 68 | 66 | 65 | 65 | 64 | 66 | 63 |
| 1933 | 64 | 56 | 54 | 63 | 56 | 52 | 59 | 60 | 64 | 63 | 63 | 62 |
| 1934 | 63 | ----- | 65 | 62 | 58 | 57 | 61 | 60 | 60 | 60 | 60 | 64 |
| 1935 | 60 | 56 | 63 | 64 | 63 | 60 | 61 | ----- | 62 | 62 | 63 | 63 |
| 1936 | ----- | ----- | 61 | 64 | 63 | 63 | 58 | 61 | 64 | 57 | 58 | 60 |
| Mean | 63.5 | 62.3 | 64.1 | 62.9 | 60.7 | 56.4 | 58.4 | 59.3 | 63.1 | 63.9 | 63.2 | 62.7 |

[1] Number of days on which observations are taken varies from month to month, and is given in reports published monthly in REVIEW.

Table 10.—*Sky polarization, percent, sun at zenith distance 60°, Madison, Wis.*

AVERAGE OF VALUES OBSERVED DURING MONTH [1]

| Year | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1917 | ----- | ----- | ----- | 57 | 54 | 59 | 59 | 66 | 66 | 67 | 59 | 71 |
| 1918 | ----- | ----- | 61 | 63 | 59 | 64 | 65 | 62 | 67 | 64 | 66 | ----- |
| 1919 | 68 | 66 | 60 | 60 | 60 | 47 | 56 | 61 | 67 | 66 | 70 | ----- |
| 1920 | ----- | ----- | 62 | 66 | 56 | 70 | 55 | 58 | 69 | 63 | 76 | 71 |
| 1921 | 72 | 65 | 69 | 60 | 66 | 64 | 65 | 57 | 69 | 68 | 70 | 72 |
| 1922 | ----- | ----- | 61 | 61 | 60 | 53 | 70 | 55 | 64 | 70 | 71 | ----- |
| 1923 | ----- | ----- | ----- | 58 | 61 | 52 | 59 | 66 | 65 | 64 | ----- | 72 |
| 1924 | 51 | ----- | ----- | 64 | 58 | 60 | 60 | 65 | 68 | 62 | 65 | 67 |
| 1925 | ----- | ----- | 56 | 55 | 49 | 58 | 58 | 55 | 58 | 60 | 61 | ----- |
| 1926 | ----- | ----- | ----- | 60 | 53 | 60 | 49 | 55 | 70 | 67 | ----- | ----- |
| 1927 | ----- | ----- | 61 | 62 | 57 | 60 | 57 | 64 | 69 | 69 | 73 | ----- |
| 1928 | ----- | ----- | ----- | 67 | 58 | 66 | 61 | 67 | 66 | 69 | 75 | ----- |
| 1929 | ----- | ----- | 73 | 63 | 54 | 56 | 62 | 51 | 59 | 60 | 65 | ----- |
| 1930 | ----- | ----- | ----- | 58 | 55 | 57 | 61 | 48 | 60 | 55 | 62 | 71 |
| 1931 | ----- | ----- | 66 | 55 | 53 | 54 | 60 | 62 | 61 | 65 | 72 | 72 |
| 1932 | ----- | ----- | ----- | 60 | 60 | 62 | 60 | 59 | 60 | 58 | 67 | ----- |
| 1933 | ----- | ----- | ----- | 59 | 59 | 60 | 64 | 63 | 68 | 69 | 64 | 72 |
| 1934 | ----- | ----- | 60 | 56 | 52 | 65 | 58 | 47 | 57 | 52 | 53 | ----- |
| 1935 | ----- | ----- | ----- | 51 | 59 | 62 | 58 | 54 | 60 | 69 | 67 | 61 |
| 1936 | ----- | ----- | ----- | 63 | 60 | 64 | 50 | 44 | 62 | 60 | 60 | 66 |
| Mean | 63.7 | 65.5 | 62.9 | 59.9 | 57.2 | 59.6 | 59.4 | 58.0 | 64.2 | 63.6 | 66.4 | 69.5 |

MAXIMUM VALUE OBSERVED DURING MONTH [1]

| Year | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1917 | ----- | ----- | ----- | 67 | 64 | 66 | 71 | 71 | 76 | 71 | 71 | 73 |
| 1918 | ----- | ----- | 71 | 67 | 65 | 69 | 72 | 71 | 74 | 69 | 73 | ----- |
| 1919 | 70 | 68 | 65 | 66 | 67 | 57 | 68 | 71 | 73 | 71 | 73 | ----- |
| 1920 | ----- | ----- | 67 | 68 | 67 | 72 | 69 | 72 | 75 | 76 | 79 | 71 |
| 1921 | 76 | 73 | 72 | 67 | 70 | 66 | 70 | 70 | 76 | 74 | 70 | 72 |
| 1922 | ----- | ----- | 61 | 70 | 66 | 71 | 72 | 72 | 74 | 74 | 72 | ----- |
| 1923 | ----- | ----- | ----- | 65 | 70 | 65 | 61 | 74 | 71 | 68 | ----- | 72 |
| 1924 | ----- | ----- | ----- | 69 | 64 | 71 | 70 | 71 | 71 | 66 | 66 | 67 |
| 1925 | ----- | ----- | 64 | 60 | 60 | 62 | 64 | 65 | 66 | 67 | 66 | ----- |
| 1926 | ----- | ----- | ----- | ----- | 63 | 64 | 65 | 64 | 72 | 70 | ----- | ----- |
| 1927 | ----- | ----- | 69 | 65 | 64 | 65 | 69 | 70 | 73 | 76 | 73 | ----- |
| 1928 | ----- | ----- | ----- | 72 | 68 | 70 | 72 | 77 | 73 | 77 | 76 | ----- |
| 1929 | ----- | ----- | 73 | 67 | 63 | 61 | 65 | 63 | 69 | 70 | 72 | ----- |
| 1930 | ----- | ----- | ----- | 70 | 63 | 69 | 68 | 59 | 70 | 61 | 68 | 71 |
| 1931 | ----- | ----- | 66 | 66 | 60 | 61 | 70 | 70 | 71 | 76 | 75 | 77 |
| 1932 | ----- | ----- | ----- | 65 | 66 | 73 | 67 | 64 | 69 | 60 | 67 | ----- |
| 1933 | ----- | ----- | ----- | 61 | 70 | 71 | 72 | 74 | 77 | 76 | 65 | 74 |
| 1934 | ----- | ----- | 60 | 64 | 61 | 70 | 64 | 61 | 63 | 57 | 57 | ----- |
| 1935 | ----- | ----- | ----- | ----- | 70 | 67 | 66 | 58 | 76 | 77 | 69 | 61 |
| 1936 | ----- | ----- | ----- | 71 | 67 | 66 | 59 | 57 | 69 | 64 | 70 | 66 |
| Mean | 73.0 | 70.5 | 66.8 | 66.7 | 64.4 | 67.0 | 67.8 | 67.7 | 71.9 | 70.0 | 70.1 | 70.4 |

[1] Number of days on which observations are taken varies from month to month, and is given in reports published monthly in Review.

Table 11.—*Comparison of blueness of sky with sky polarization and visibility, Washington, D. C.*

| Blueness of sky | Percent of polarization | Visibility, miles | Number of observations |
|---|---|---|---|
| 2 | 11.0 | 1.0 | 1 |
| 3 | 44.1 | 10.5 | 11 |
| 4 | 51.7 | 16.5 | 145 |
| 5 | 57.0 | 25.6 | 292 |
| 6 | 59.3 | 38.1 | 120 |
| 7 | 62.1 | 43.9 | 15 |
| 8 | 65.5 | 50.0 | 2 |

Table 12.—*Dust content of the atmosphere at American University, District of Columbia, at 8 a. m., particles per cubic centimeter*

MONTHLY MEANS

| Year | January | February | March | April | May | June | July | August | September | October | November | December | Annual means |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1922 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 1,228 | ----- |
| 1923 | 1,061 | 905 | 540 | 476 | 393 | ----- | 397 | 388 | 386 | 395 | 451 | 557 | 540 |
| 1924 | 719 | 533 | 409 | 645 | 376 | 420 | 539 | 326 | 335 | 598 | 1,110 | 1,159 | 597 |
| 1925 | 723 | 1,092 | 909 | 753 | 416 | 507 | 480 | 484 | 514 | 608 | 787 | 1,444 | 726 |
| 1926 | 1,631 | 1,517 | 1,370 | 755 | 573 | 578 | 542 | 532 | 565 | 692 | 851 | 1,056 | 888 |
| 1927 | 1,011 | 1,116 | 939 | 721 | 729 | 607 | 933 | 760 | 859 | 1,021 | 1,097 | 1,176 | 914 |
| 1928 | 1,455 | 1,450 | 1,232 | 856 | 668 | 596 | 757 | 675 | 774 | 1,082 | 979 | 1,227 | 978 |
| 1929 | 1,419 | 1,086 | 652 | 610 | 621 | 469 | 549 | 626 | 638 | 616 | 858 | 881 | 752 |
| 1930 | 898 | 736 | 668 | 753 | 614 | 544 | 573 | 828 | 866 | 1,020 | 995 | 875 | 781 |
| 1931 | 906 | 951 | 809 | 815 | 608 | 631 | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| Average | 1,091 | 1,043 | 836 | 709 | 555 | 544 | 596 | 577 | 617 | 754 | 891 | 1,047 | 772 |

MAXIMA

| Year | January | February | March | April | May | June | July | August | September | October | November | December | Annual means |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1922 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 2,088 | ----- |
| 1923 | 3,680 | 2,050 | 1,155 | 1,182 | 905 | ----- | 793 | 794 | 812 | 853 | 1,023 | 2,340 | 1,394 |
| 1924 | 2,403 | 1,964 | 1,280 | 1,661 | 1,154 | 1,250 | 1,953 | 796 | 823 | 1,366 | 1,987 | 2,551 | 1,595 |
| 1925 | 1,352 | 2,370 | 2,247 | 7,077 | 781 | 991 | 1,016 | 1,037 | 1,109 | 1,432 | 1,558 | 3,106 | 2,006 |
| 1926 | 3,828 | 2,995 | 2,999 | 1,527 | 1,042 | 1,035 | 985 | 941 | 1,073 | 1,426 | 3,975 | 2,388 | 2,018 |
| 1927 | 3,511 | 2,474 | 1,877 | 1,588 | 1,529 | 1,560 | 1,651 | 1,443 | 1,672 | 3,133 | 2,566 | 2,984 | 2,168 |
| 1928 | 3,620 | 3,557 | 2,617 | 2,039 | 1,575 | 1,434 | 1,308 | 1,302 | 1,493 | 2,772 | 2,751 | 4,116 | 2,382 |
| 1929 | 3,620 | 1,982 | 1,583 | 1,153 | 1,032 | 897 | 922 | 976 | 1,010 | 1,098 | 1,628 | 1,606 | 1,463 |
| 1930 | 3,780 | 1,512 | 1,176 | 1,166 | 1,701 | 855 | 1,052 | 1,323 | 1,426 | 2,066 | 1,953 | 1,779 | 1,649 |
| 1931 | 1,617 | 1,649 | 1,352 | 1,434 | 846 | 1,073 | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| Average | 3,046 | 2,284 | 1,810 | 2,089 | 1,179 | 1,137 | 1,210 | 1,076 | 1,177 | 1,761 | 2,180 | 2,551 | 1,792 |
| Absolute maximum | 3,828 | 3,557 | 2,999 | 7,077 | 1,701 | 1,560 | 1,953 | 1,443 | 1,672 | 3,133 | 3,975 | 4.116 | ----- |

MINIMA

| Year | January | February | March | April | May | June | July | August | September | October | November | December | Annual means |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1922 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | 298 | ----- |
| 1923 | 214 | 105 | 113 | 113 | 65 | ----- | 90 | 110 | 59 | 96 | 71 | 90 | 108 |
| 1924 | 124 | 97 | 76 | 151 | 124 | 155 | 124 | 87 | 97 | 155 | 113 | 124 | 118 |
| 1925 | 57 | 77 | 87 | 202 | 149 | 197 | 132 | 143 | 118 | 130 | 124 | 344 | 147 |
| 1926 | 160 | 298 | 223 | 227 | 187 | 214 | 218 | 145 | 132 | 82 | 76 | 145 | 176 |
| 1927 | 155 | 185 | 145 | 138 | 225 | 122 | 288 | 187 | 218 | 99 | 172 | 143 | 173 |
| 1928 | 160 | 254 | 162 | 174 | 126 | 202 | 384 | 132 | 126 | 334 | 120 | 109 | 190 |
| 1929 | 160 | 200 | 101 | 242 | 134 | 128 | 170 | 191 | 176 | 124 | 323 | 204 | 179 |
| 1930 | 361 | 253 | 237 | 241 | 134 | 178 | 150 | 144 | 278 | 384 | 231 | 376 | 247 |
| 1931 | 372 | 369 | 174 | 233 | 275 | 216 | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| Average | 196 | 204 | 146 | 191 | 158 | 176 | 194 | 132 | 150 | 176 | 154 | 204 | 174 |
| Absolute minimum | 57 | 77 | 76 | 113 | 65 | 122 | 90 | 87 | 59 | 82 | 71 | 90 | ----- |

# FLOODS IN THE SACRAMENTO VALLEY, CALIF., DECEMBER 1937

By E. H. Fletcher

[Weather Bureau, Sacramento, Calif., January 1938]

December 1937 will be epochal in the history of the floods of the Sacramento Valley in that it produced the highest stages in the river system above the mouth of the American River since the beginning of Weather Bureau records in 1904, and, from all indications, exceeded the high water of 1862 in the upper valley.

During the first week in October there were unprecedentedly heavy rains, for so early in the season, in the upper Sacramento River basin. A long period of protracted, heavy rainfall followed in November and resulted in the highest water of record for the season in that river.

In past years no great flood has ever been known to occur in December. This year, however, the ground was well saturated at the end of November and the stream channels and bypasses were still carrying considerable water. This condition, together with the fact that the earlier fallen snow had receded to high altitudes, constituted a favorable situation for a high percentage of immediate run-off from rainfall, there being no retarding influence occasioned by a heavy snow cover.

On December 9, a center of low barometric pressure of unusual potentialities was located about 700 miles off